Inmetro 10 V Programmable Josephson Voltage Standard Implementation

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***Abstract* — This paper describes the implementation of a 10 V Programmable Josephson Voltage Standard (PJVS) at Inmetro. The PJVS details as well as dc, ac and Zener calibration preliminary results are presented.**

***Index Terms* — Precision measurements, Programmable Josephson Voltage Standard, Zener calibration.**

I. INTRODUCTION

Since the SI unit for electromotive force (volt) definition ratified by the 9th CGPM (in 1948), whose realization to high accuracy is difficult and time consuming [1], Weston cells and after that (in the early 1970s) the Josephson effect were used as the practical standard of voltage by many national standards laboratories [2]. In the latter case, the conventional Josephson Voltage Standard (JVS) systems provide a voltage calculated by $V = n.f/K_{J\text{-}90}$, where n is the number of the active steps, f is the irradiated microwave frequency and $K_{J\text{-}90}$ is the Josephson constant (483 597.9 GHz/V).

The conventional JVSs, however, have two important disadvantages: (1) the step number cannot be quickly set to a desired value and (2) noise may cause spontaneous transitions between steps [2]. In order to address these problems, one of the proposed solutions was a Programmable JVS (PJVS), which can produce stable programmable dc voltages. It consists of a series array of *M* nonhysteretic junctions (SINIS structure), divided into smaller independently biased segments (sub-arrays). Since each one of these sub-arrays are connected in series and they can be independently biased to the +1, 0 or -1 steps, the output voltage can be programmed by adding or subtracting the voltage of each sub-array. So, a combination of +1, 0 or -1 steps for each sub-array (or a "state" of the array) can be programmed and it will result in a given output voltage.

If a rapid succession of those states is programmed, the PJVS can generate a succession of dc voltages, synthesizing ac voltages. Such PJVS feature has been used for many other applications, like fast-reversed dc comparisons between Josephson sources and thermal voltage converters, and later as sinewaves for highly accurate ac-dc difference measurements at frequencies up to 1 kHz (limited by step transition), as well as to applying PJVS stepwise-synthesis techniques to the development of quantum-based power standards [3].

The National Institute of Metrology, Quality and Technology (Inmetro) is the Brazilian national metrology institute responsible for realization, maintenance and dissemination of S.I. units as well as for the custody, preservation and traceability of national standards of the related quantities.

In 1998 Inmetro implemented its first conventional JVS system (at 1.018 V), in collaboration with the National Institute of Standards and Technology (NIST). Currently, Inmetro uses a 10 V conventional JVS to provide dc voltage traceability. Considering the possibility of achieving a few parts in 10^{11} V/V (in a direct comparison at 10 V dc between two PJVSs) and the generation of ac voltages by a PJVS, Inmetro is implementing its PJVS (NIST technology-based), in collaboration with the NIST. Inmetro PJVS details, dc, ac and Zener calibration results are shown in the next sections.

II. INMETRO PJVS SYSTEM

Inmetro PJVS system uses a (NIST) 10 V SINIS array (sn. 10F_110113-21), 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 (composed by 24 optically isolated DACs). The RF source is an Agilent E8257D PSG Microwave Analog Signal Generator (capable of reaching up to 31 GHz and having 0.001 Hz resolution) [3]. A Symmetricon 571A cesium atomic clock (electrically isolated) provides a 10 MHz reference to the RF source. Step biasing, array monitoring and the connection of the Zener under test are operated automatically by the softwares PJVS2011 (from NIST/Metas) and Nistvolt-P (from NIST) in a computer (PC). The bias source is always connected (what ensures the step stability) and the array is floating with respect to ground, which means the measurement ground reference point can be chosen arbitrarily. 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. The laboratory temperature is regulated to better than ± 1 ^{o}C (what minimizes the thermal voltages and ensures good voltage stability during the measurements). The system is powered by an exclusive UPS through an isolator transformer. Although our chip's SbA01 to SbA07 are not functional, the sub-arrays who work allow the array to provide 10 V. Fig. 1 shows a simplified block diagram for Inmetro PJVS system.

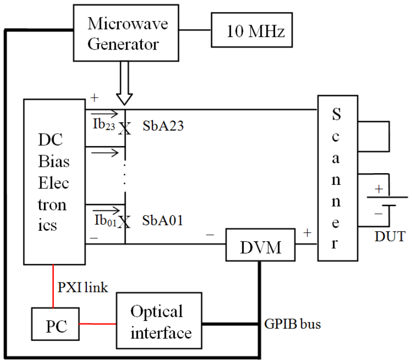

Fig. 1. Block diagram for Inmetro PJVS system in a Zener calibration (optical links in red).

The PJVS high accuracy output dc voltage is only possible if it works within the stable steps limits. Hence, for each operating point (defined by the frequency and by the microwave power) an off-line adjustment is needed in order to (1) characterize the PJVS sub-arrays margins (positive and negative first steps width), measuring the steps limits and the optimum bias currents, and (2) create a table with the array "states" (which sub-array has +1, 0 or -1 active steps). Due to SbA01 to SbA07 limitation, experimental tests show our PJVS array has a very good performance at 18.72 GHz/+2 dBm (for 10 V) and at 18.20 GHz/+1 dBm (for 1.018 V), presenting margins above 1.25 mA and reaching values close to the nominal. Those were the operating points used in this work.

A. DC Voltages Generation

Once defined the desired dc voltage to be generated by the PJVS, the correct state is chosen from the table created off-line and the adequate bias current is applied to each sub-array. This will instantly generate the desired voltage. For instance, to generate 10.008 624 106 9 V at 18.72 GHz, our array must be at the state "00000001111111111111111", regarding the SbA01 to SbA23, respectively, from the left to the right.

B. Stepwise AC Voltages Generation

If adequate dc voltages are generated successively and quickly, an arbitrary stepwise ac voltage can be generated by the PJVS. Once the waveform type, its output value, frequency and number of steps are defined, a table with all the sub-arrays states at each waveform instant is sent to the PXI memory, which will bias the array properly. Fig. 2 shows a 10 V peak, 1 kHz, sinusoidal waveform generated by the Inmetro PJVS.

C. Zener Calibration

Zener calibration is performed using the differential comparison method, usual in accurate dc voltage measurements (Fig. 1). Hence, the DVM is used in the lowest range possible, increasing the accuracy of the measurement. A mathematical model of the calibration circuit (Fig. 1) is solved by the Least Squares Estimation technique using the measured values, providing the DUT voltage value [4].

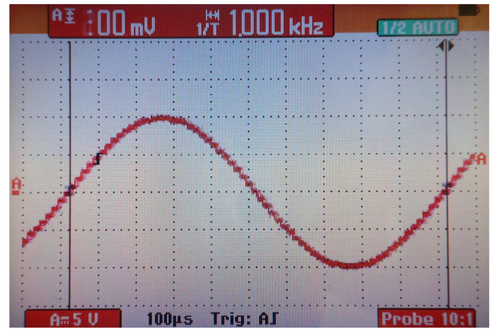

Fig. 2. 10 V peak, 1 kHz, Sinusoidal PJVS Output Voltage

Some indirect comparisons were made between our PJVS and our conventional JVS in January, 2012 (from 12th to 20th), using the same Zener. The difference between them (day by day) was within 105 nV (at 1.018 V) and 520 nV (at 10 V), showing that some improvements still need to be done in the PJVS measurement loop. The PJVS type A uncertainty (k=1) was within 5.3 nV (at 1.018 V) and 36.0 nV (at 10 V). PJVS Combined Standard Uncertainty (CSU) is 15.0 nV (at 1.018 V) and 38.6 nV (at 10 V), according to [4]. Results of a direct comparison between the two systems are presented in [5].

IV. Conclusion

Inmetro PJVS implementation is ongoing. Preliminary results of dc, ac and Zener calibration at 1.018 V and 10 V were presented, as well as Inmetro PJVS details, showing it is working properly and it can be used in regular Zener calibration.

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