First direct DC 10 V comparison between two Programmable Josephson Voltage Standards made of (NbN)-based and amorphous niobium silicon (Nb_xSi_{1-x}) Josephson Junctions

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Abstract: The new BIPM primary travelling standard for which the array is made of amorphous niobium silicon Nb_xSi_{1-x} Josephson Junctions (JJ) has been directly compared to a NMIJ array of (NbN)-based JJ. The results show an excellent agreement of 5 parts in 10^{12} with a total combined uncertainty of less than 1 part in 10^{10}. As the low side of the NMIJ array is always connected to the reference potential of the measurement setup, we investigated possible systematic errors due to the leakage resistance to ground (LRG). The results show that a compromise needs to be found between the width of the quantum voltage step, ie noise reduction efficiency and the systematic voltage error introduced by the filter (capacitance LRG and line resistance of the precision leads).

1. INTRODUCTION

The BIPM has begun two pilot studies with its new transportable primary voltage standard based on a programmable Josephson junctions array (PJVS). The aim is to confirm that this new system could offer state-of-the-art of accuracy when operated as a transfer standard in the framework of the BIPM.EM-K10.a & b comparisons. Agreement between the current BIPM travelling standard based on an SIS Josephson junctions array [1] and the new system has already been achieved to 8 parts in 10^{12} in BIPM laboratories. The new PJVS for which the array is made of amorphous niobium silicon Nb_xSi_{1-x} Josephson Junctions (JJ) has been shipped to NMIJ (Japan) where a direct comparison has been conducted with a NMIJ array of (NbN)-based JJ. Those two different technologies have been compared for the first time at 10 V. Particular attention was given to the possible dominant source of systematic error arising from the operations of PJVS: leakage resistance to ground.

2. DESCRIPTION OF THE TWO PJVS AND MEASUREMENT SETUP

2.1. NMIJ PJVS

The NMIJ PJVS array is composed of a total of 524 288 NbN-based overdamped JJ. This allows a DC voltage of up to 17 V to be generated at a frequency of f=15.7 GHz with a resolution of 12 bits. During operation, the array is cooled down to a temperature of 10 K with a Gifford MacMahon (GM) liquid-helium-free, cryocooler [2-3]. The RF source is a commercial signal generator with an external amplifier, The PJVS voltage is controlled using a custom-made 24 channel current source.

2.2. BIPM PJVS and Measurement setup

The new BIPM transportable PJVS is based on the NIST-design PJVS [4], using a JVS-650 bias source and for which the total number of junctions with all subarrays in series is 248 312. The RF source is a compact synthesizer which is located in the bias source chassis. The measurement setup is identical to the one operated in the BIPM on-site Josephson comparisons [5]: the two PJVSs were connected in series opposition, with the positive potential sides directly connected and the null detector inserted between the two low-potential sides (Fig. 1).

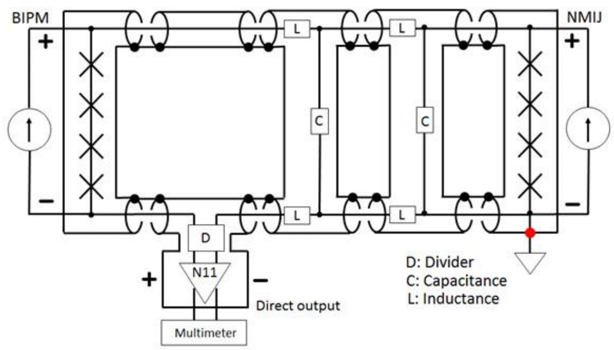

Fig. 1. *Schematic of the comparison setup for the direct comparison of the two PJVS. A two-stage inductance-capacitance (LC) filter is inserted on NMIJ side*.

3. RESULTS OF THE COMPARISON AND INTERPRETATION

3.1. Measurements results

The first measurement results showed a repeatable systematic error of the amplitude of 6 nV in the direction of a possible leakage error on the NIMJ output leads. When removing one of the two filters from the output measurement leads, the systematic error dropped down to 4 nV. Moreover, when the filters were removed, the PJVS arrays agree to 5 parts in 10^{12}.

In our experiment, the low side of the NIMJ array was grounded and therefore offered an ideal path for the leakage current. This is consistent with the assumption of a leakage error on the two-stage filters located at the output of the NMIJ measurement leads.

3.2. Leakage to ground systematic error

The systematic voltage error is produced by the leakage current of the measurement setup flowing through a weak leakage resistance. In the present case, this resistance is the dielectric resistance of the capacitances of the filter installed on the precision output leads of the NMIJ PJVS. The systematic error ie voltage drop across the output filter is proportional to the ratio of the resistance in line (r) to the leakage resistance (R_L) and the PJVS nominal voltage [6]. Figure 2 shows the voltage difference recorded between the two PJVS as a function of the comparison nominal voltage. The absolute value of the slope of the linear fit, $(r/R_L) = (0.6 \pm 0.1) \times 10^{-9}$, confirms a leakage resistance of 33 GΩ if the line resistance is 20 Ω.

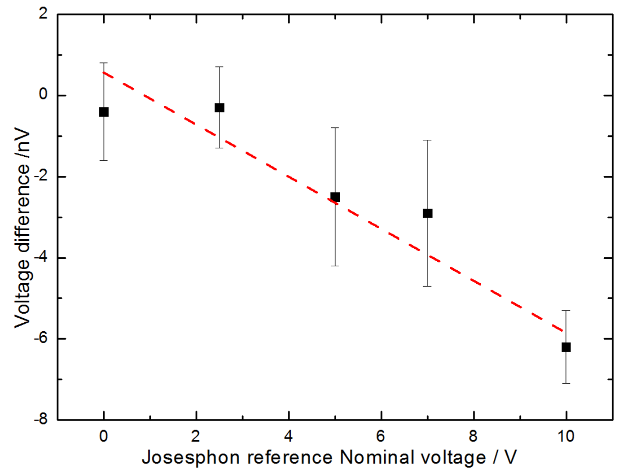

Fig. 2. *Voltage difference between the two arrays as a function of the PJVS nominal voltage. The uncertainty bars represent the Type A uncertainty (k = 1). The dashed line is a linear fit applied to the experimental data.*

4. CONCLUSION

For the first time, an NMIJ PJVS and the new transportable BIPM PJVS based on the NIST-designed quantum voltage standard were compared directly at 10 V. Although the results exhibit an excellent agreement to 5 parts in 10^{12}, we found that the insertion of an (L,C) filter at the output of the measurement leads of the NMIJ array causes a double effect: it improves the quantum voltage step width by preventing any AC noise to the array [7] but also introduces a systematic error (up to 8 nV) proportional to the ratio of the resistance in line (r), the capacitance leakage resistance (R_L) and the PJVS nominal voltage. A compromise must therefore be made between the filtering efficiency to obtain larger margins and the possible systematic voltage error that can be achieved on the generated voltage.

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