Towards a Quantum Sampling System

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***Abstract*—This summary paper describes the development of a system based on the Josephson effect, to calibrate and characterize voltage standards and digital sampling systems. In particular, this work includes the test of a digital-to-analog converter as a source to bias the segments of the programmable Josephson array.**

***Index Terms*—Voltage measurement, Josephson effect, Measurement standards, Analog-digital conversion, Metrology.**

I. Introduction

Application of Josephson Voltage Standards (JVS) to reproduce the unit volt is nowadays widely spread within the National Metrology Institutes. It is also the cornerstone of modern precision instrumentation due to its unique capabilities to characterize analog-to-digital converters. The Josephson effect and its application to the electrical metrology is well described in the bibliography, see [1] as an example.

INTI has started in June 2015 to upgrade its Josephson system to a Programmable Josephson Voltage Standard (PJVS) and towards a quantum sampling system based on a previous work [2]. The first step was to test a 1 V programmable Josephson array modifying the conventional Josephson system available at INTI. Second a self-made fully programmable current source has been tested as a bias source for the binary segments of the Josephson array. Third, a digital sampling system based on sigma-delta ADC has been verified with AC and DC voltages.

II. System Overview

The upgrade of the INTI conventional Josephson system to a 1 V programmable Josephson voltage standard is ongoing. The first tasks are described in this section.

A. Upgrade of the conventional 1 V Josephson system

The INTI conventional Josephson system has been upgraded to a 1 V PJVS. To accomplish this, the cryoprobe was slightly modified as follows: the high frequency filters at the front-end were bypassed and the connections to the bias sources were removed to use all the remaining wires to connect the array segments. Then, the bias sources were replaced by a new model which can deliver more current. The 70 GHz Gunn diode oscillator, the phase locked loop and the microwave attenuator were kept unchanged.

B. Programmable Josephson array configuration

The 1 V programmable array [3], built at PTB, has 8192 SNS Josephson junctions (JJ) divided into 14 binary segments in the sequence shown in Fig. 1. Since the cryoprobe of the conventional JVS system has 8 wires, only 6 bias connections are available. The voltage across the complete array uses two additional wires. The chosen configuration allows to perform the projected tests and is depicted in Fig. 1.

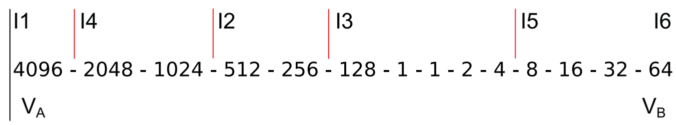

Fig. 1. Arrangement of the array segments sequence. The connections to the bias source are indicated as I1 to I6. V_A and V_B indicate the output voltage wires.

C. Programmable current source

The current source is constructed connecting a 50 Ω resistor in series to the output of a real-time programmable voltage source, designed for a cryogenic current comparator and described in [4]. This source can generate DC voltages, square and triangle waveforms using a commercially available R-2R DAC with 20-bits resolution, ±5 V dynamic range and a slew rate of 50 V/μs. On this application the working sampling frequency is set to 100 kHz with an output amplitude of ±1.2 V. The DAC is controlled by a CPLD running at 66 MHz clock frequency via an isolated serial communication of 121 ns per bit.

III. Preliminary Measurement Results

Different tests were performed in order to check the modified system capabilities.

A. Zener comparison

The system was configured to obtain an output voltage of 1.018 V using the segments I1-I2 (7168 JJ, see Fig. 1), biased manually, and I3-I5 (136 JJ) biased with the DAC. The center of the step has been checked with a high resolution voltmeter.

Then, using a sequence which includes polarity reversals, gave a result of:

$$\delta = \frac{U_{Z_{PJVS}} - U_{Z_{JVS}}}{U_{Z_{JVS}}} = 85 \text{ nV/V}, \tag{1}$$

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where $U_{Z_{PJVS}}$ is the Zener voltage obtained with the programmable system and $U_{Z_{JVS}}$ is the last voltage calibrated with the conventional system one month before with an uncertainty of 100 nV/V (k=2).

B. Thermal voltages measurement

In order to characterize the system the thermal voltage has been measured in both polarities. To do so, segments I1-I4 and I4-I6 were connected in series-opposition. The resulting voltage was measured using a digital nanovoltmenter. Then, the bias currents through the segments have been reversed and the voltage was measured. Table I presents the results for both polarities.

TABLE I
THERMAL E.M.F. RESULTS. MEASURED VALUES ARE THE AVERAGE OF THE NANOVOLTMETER READOUTS.

Polarity	Measured Values (nV)	Standard deviation (nV)
POL-	-29.3	2.3
POL+	-10.5	1.3

C. Transients

Signal transients were measured in order to establish the frequency limit. The current source was applied to the full array in order to produce a 2 V peak-to-peak change. The step transients have been observed and measured using a digital oscilloscope. A transient of 5 μs was obtained as depicted in Fig. 2.

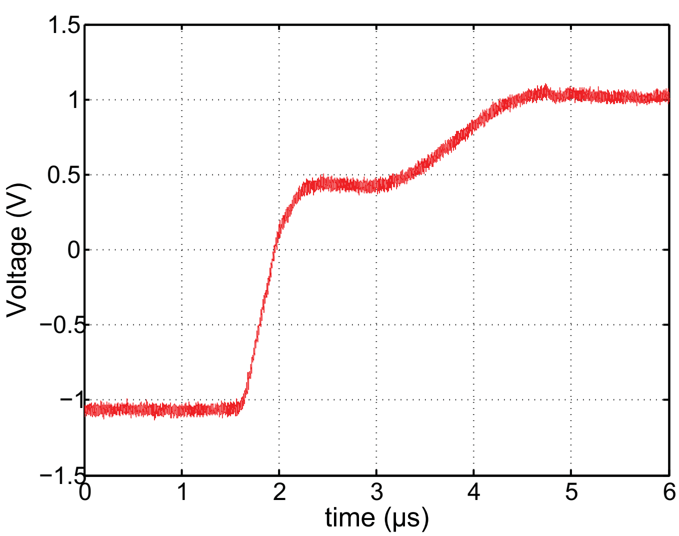

Fig. 2. Step transient of a square waveform. The settling time is around 5 μs.

D. Sigma-Delta ADC sampling system verification

The sampling system based on a 24-bits sigma-delta ADC described in [5] was calibrated with the PJVS for AC and DC voltages as follows: for AC voltage a square waveform of 100 Hz has been synthesized to obtain the AC correction, δ_{AC}. Then, the amplitude of the square waveform was applied as a DC voltage and a DC correction, δ_{DC}, was calculated with a standard deviation of 8 μV/V. Finally, an AC/DC calibration difference was obtained as:

$$\gamma = \frac{\delta_{DC} - \delta_{DC}}{\delta_{DC}} = -1.2\ \mu\text{V/V}. \quad (2)$$

This value is in agreement with the results presented in [5], [6], where the sampling system measured a signal of 1 V peak voltage at 125 Hz with a combined uncertainty of 4.5 μV/V.

IV. CONCLUSION AND FUTURE TRENDS

The tests presented in this summary have fulfilled our expectations. The development is ongoing on a two year schedule. The next step is to add more channels to the programmable current source in order to use all the segments which are now connected. These channels will act synchronously in real-time to obtain different signal waveforms at different frequencies and amplitudes. Finally, a new cryoprobe will be constructed in order to use the 14 segments in the array. At the conference we will report the progress of the work.

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