Simultaneous Double Waveform Synthesis with a Single Programmable Josephson Voltage Standard

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***Abstract* — We have recently demonstrated new 2 V PJVS devices configured with two voltage outputs and two sets of least significant bits in order to simultaneously generate two independent stepwise output waveforms. This development improves upon our previous alternating dual waveform method in that the two voltage waveforms can now be measured simultaneously, and the sampler overload condition that existed in the previous configuration has been eliminated. Applications such as the NIST Quantum Watt for ac power calibrations will benefit from these developments through reduced measurement uncertainties and improved flexibility.**

***Index Terms* — Josephson arrays, Signal sampling, Standards, Power Measurement, Voltage Measurement.**

I. Introduction

Programmable Josephson voltage standards (PJVS) have improved continuously since 1995 [1]. Besides dc voltage metrology applications in which the 10 V PJVS systems are commonly used, PJVS systems with lower output voltage (1 V or 2 V) are implemented in other applications such as the electronic kilogram programs and in low-frequency ac electric power programs, such as the NIST Quantum Watt [2].

The Quantum Watt requires two independent low harmonic distortion voltage sources with typical rms amplitudes of 1.2 V and 0.5 V. These two reference sources are utilized to measure, respectively, the voltage and the current components of electric power. Presently, the rms value of each source is alternately measured using the differential sampling method and a multi-period reference waveform generated by a single PJVS [3].

This paper presents a new method to simultaneously synthesize two voltage waveforms from a single 2 V PJVS circuit recently developed at NIST. The advantage of this method is the new ability to simultaneously measure the voltage and current waveforms with a single PJVS system, which reduces both the complexity and operating costs of the Quantum Watt.

II. 2 V PJVS Array

We have developed a 2 V PJVS superconducting integrated circuit containing 61 204 Josephson junctions (JJs) that are capable of generating a maximum dc output voltage of ±2.278 V when biased at a microwave frequency of 18 GHz (Fig. 1). The circuit is equipped with two full and identical sets of least significant bits (LSBs), one on each extremity of the chip, that are each subdivided in a ternary sequence. The smallest LSB contains four JJs in a single segment, which is made from a pair of double stack $Nb/Nb_xSi_{1-x}/Nb/Nb_xSi_{1-x}/Nb$ junctions. The mirrored distribution of the subarrays across the chip allows for a perfect 0 V output during dither current flat-spot measurements when the symmetric matching subarrays are biased alternately on the $n = \pm 1$ steps. These circuits are capable of operating over a wide microwave frequency range from 15 GHz to 21 GHz.

An extra common voltage tap was added to this new 2 V PJVS circuit to allow the top and bottom array subsections to produce independent voltage outputs. The dc-current-bias electronics developed for the NIST 10 V PJVS, which contains 24 digital-to-analog converter (DAC) voltage sources each with a 112 Ω bias resistor, is fully compatible with the 20 subarrays of the new 2 V PJVS circuit. Figure 2 shows a flat-spot width of 1.75 mA measured with nanovolt resolution.

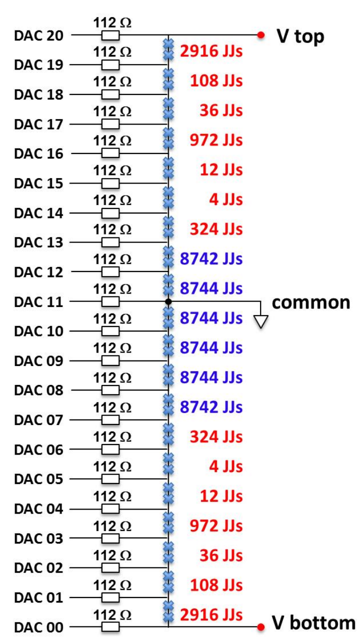

Fig. 1. Block diagram of the 2 V PJVS circuit, illustrating the two sets of LSBs (number of JJs in red), the current bias leads (left side), and the voltage output taps (right side).

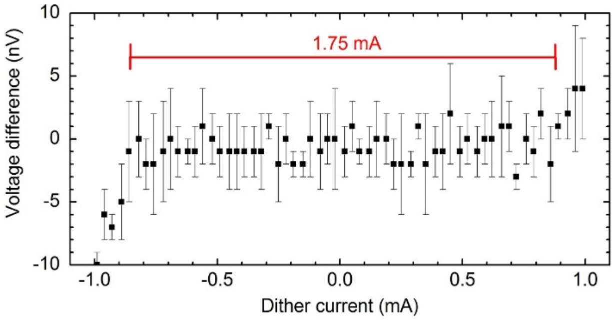

Fig. 2. Dither current flat-spot measurement performed with the first half of the 2 V subarrays biased on the $n = +1$ step and the second half biased on the $n = -1$ step. The error bars represent the standard deviation (k=1) of four measurements.

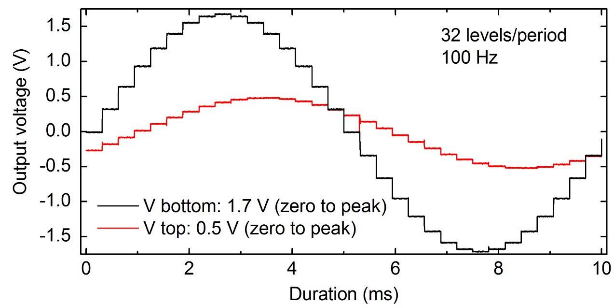

Fig. 3. Example of simultaneously-measured oscilloscope traces of the PJVS output voltages V_{top} and V_{bottom}. The two stepwise-approximated PJVS waveforms shown have 32 levels each, and a frequency of 100 Hz. The relative phase difference between the two waveforms is software selectable, and in this example is 30 degrees.

III. Double Waveform Synthesis

In order to generate two independent voltage outputs from a single chip, the array circuit is divided into two sections separated by the common tap (Fig. 1). The bottom and top sections, respectively, contain 39 346 JJs and 21 858 JJs. When biased with a microwave frequency of 20.86 GHz, the peak voltages for each section are $V_{bottom} = 1.697$ V and $V_{top} = 0.943$ V. These values enable the PJVS to simultaneously generate the two stepwise-approximated reference sinewaves with rms amplitudes of 1.2 V and 0.5 V that are required for the NIST Quantum Watt.

To implement this double voltage waveform synthesis, some simple hardware modifications were made to the existing NIST PJVS system. Two additional twisted pair voltage outputs run from the chip to room temperature, and their corresponding two coaxial output connectors (for V_{top} and V_{bottom}) are mounted on the cryoprobe. The connector outer shields share the on-chip common node.

The software was modified to generate arbitrary waveforms for the two outputs. At each step in the waveform sequence the array common node adjacent to DAC 11 (denoted by the black dot in Fig. 1) is kept at a potential of 0 V, which limits the capacitive loading effect of the bias electronics power supply. The bias electronics are fully isolated from earth ground, so the user can choose whether or not to ground the common node for a given application. Since a single microwave source is used to bias both sections of the array, fine adjustment of the voltage by slightly detuning the microwave frequency can only be performed relative to a single output. Both waveforms are loaded simultaneously and share the same clock signal. Relative phase adjustment between the two waveforms is achieved by adjusting the waveform data with a resolution of 172.5 µV (4 JJs), as shown in Fig. 3.

IV. Application to the Quantum Watt

As presently implemented in the Quantum Watt, the PJVS reference waveform alternates between the two waveform amplitudes every 16 to 20 periods [3], due to the finite 2048 sample size of the DAC biases. As a result, the acquisition time of the differential voltage is reduced, increasing the Type-A uncertainty on the signal of interest [4]. Furthermore, each sampling voltmeter is overloaded half of the time, requiring some time (typically one period of the signal of interest) to recover [3]. The new circuit, with dual waveform synthesized output signals eliminates these two limitations. Our next step will be to integrate the simultaneous double PJVS reference waveforms into the Quantum Watt measurement apparatus, utilizing two sinusoidal reference voltage sources and two sampling voltmeters.

V. Conclusion

The recent development of a 2 V PJVS circuit with dual voltage outputs, including two sets of LSBs, allows a single PJVS system to simultaneously generate two different output voltages. The NIST electric power standard will benefit from this new capability and measurement method, with the advantage of increasing the performance of the present differential sampling approach with minimal hardware modification. This method opens the door to new metrology applications that require two voltages, and avoids the complication and cost of two independent PJVS systems.

References

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