Advances in Technology of Precision Measurements with Josephson Circuits

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***Abstract* - In the past year, a number of metrology papers have been published that advance the state of the art both in Josephson voltage standard technology and in precision measurements for dc and ac voltage, ac impedance and Johnson noise thermometry. Their contents and main results are summarized here with links to DOI numbers of full publications.**

***Keywords* – Standard, voltage, metrology, Josephson junction, Johnson noise, thermometry, arbitrary waveform synthesis**

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Programmable Voltage Standards

Development of a cryocooled niobium-based 10 V programmable Josephson voltage standard (JVS) enabled NIST researchers to fully automate quantum-based electrical measurements and to characterize and optimize the quantum states of over 260,000 junctions for all bias parameters and as a function of temperature [1].

Precision measurements and inter-comparisons between various types of Josephson voltage standards, either programmable or conventional JVS systems, are now routinely made at 10 V by many laboratories including the Bureau International des Poids et Mesures (BIPM), the Physikalisch-Technische Bundesanstalt (PTB), the National Institute of Advanced Industrial Science and Technology (AIST), and the National Institute of Standards and Technology (NIST). National Aeronautics and Space Administration (NASA) and NIST staff recently achieved agreement between such systems to a few parts in 10^{10} [2].

Arbitrary Waveform Synthesis

Improved pulse-bias techniques for arbitrary waveform synthesis with arrays of Josephson junctions have enabled reduced systematic errors for an electrical measurement of Boltzmann's constant [3], [4].

The most rapid technology advances, however, have been in increasing output voltage and bias margins for quantum-accurate ac voltage sources called Josephson arbitrary waveform synthesizers (JAWS). Quantum-accurate synthesis of 1 V rms voltages was first demonstrated in 2014 (at NIST), and it took 19 years from the invention to achieve this record output voltage. In only two additional years, NIST researchers recently doubled that output voltage to 2 V rms and also doubled the performance of the JAWS systems by doubling the current bias range for realizing quantum accuracy [5]. In fact, further performance improvements have also recently been achieved through implementation of longer arrays, broadband power splitters and FIR filters [6].

Finally, the improved JAWS performance was recently exploited in a collaboration between the Swiss Federal Institute of Metrology (METAS) and NIST. METAS researchers constructed a new fully digital impedance bridge. The METAS bridge was integrated with two of NISTS's synchronized JAWS quantum-accurate sources, which enabled the collaborators to demonstrate a new precision measurement technique that may revolutionize impedance measurement. The resulting quantum-based impedance bridge can, for the first time, compare impedances regardless of type (R-C, R-L, or L-C), with arbitrary ratios and phase angle and over a large frequency range (from 1 kHz to 20 kHz). This single bridge instrument is the first of its kind that can fully cover the entire complex plane [7].

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