Development and Applications of a Four-Volt Josephson Arbitrary Waveform Synthesizer

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***Abstract*— We have recently created a 4 V rms cryocooled JAWS (Josephson Arbitrary Waveform Synthesizer) using 204,960 nearly identical Josephson junctions (JJs) that are embedded in coplanar-wave guides. The JJs are pulse-biased at repetition rates up to 16×10^9 pulses per second to create quantum-accurate, calculable AC waveforms at frequencies from DC to greater than 1 MHz. This system has metrological applications including in precision ac voltage calibrations, comparisons of arbitrary impedances, and ac power measurements.**

Keywords*— *Metrology, digital-to-analog conversion, Josephson junction arrays, measurement standards, signal synthesis, superconducting integrated circuits, voltage measurement.

I. Introduction

Over the past thirty years, electrical metrology has been revolutionized by superconducting Josephson-junction (JJ) circuits' ability to generate quantum-accurate voltages. Circuits and systems with higher output voltage have enabled these advances in metrology. We recently doubled the output voltage of the JAWS (Josephson Arbitrary Waveform Synthesizer) system compared to previous systems [1] by developing a JAWS chip that generates dc and ac voltages up to 1 MHz with rms amplitudes up to 2 V. This performance improvement has enabled the direct calibration of new instrument ranges and has opened new applications in impedance and ac power metrology.

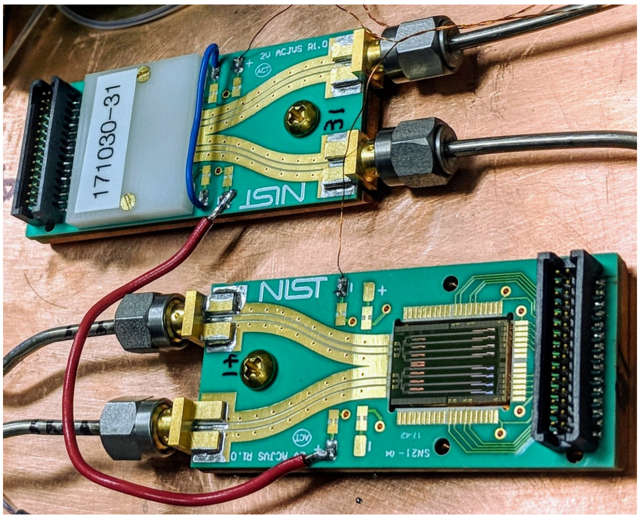

Fig. 2. Picture of two 2 V rms JAWS chips on a 4 K cryocooler

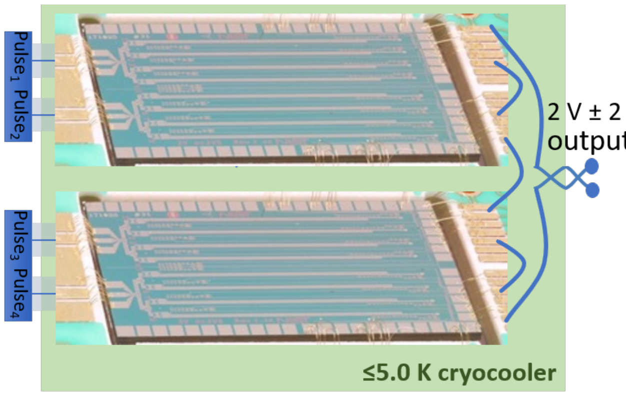

Fig. 1. Simplified system diagram of a 4 V rms cryocooled JAWS

II. Recent Progress

We created a 4 V rms cryocooled system (see Figure 1) by using two of the 2 V JAWS chips containing a combined total of 204,960 nearly identical JJs [2]. The JJs are arranged in 16 series arrays that are embedded in separate coplanar-wave guides (see Figure 2). The quantum-accurate JAWS waveforms are based on a delta-sigma encoding of the JJ voltage pulses which have an integrated area *h/2e*. The voltage pulse timing is controlled by current biasing the JJs with a programmable series of fast current pulses at up to 16×10^9 pulses per second. Each 2 V chip has two high-speed pulse inputs, each of which use two layers of superconducting Wilkinson dividers to split their respective inputs into four signals that each bias one series JJ array. To generate a quantum-accurate output voltage, each input bias pulse must induce every JJ to create a single quantized output pulse.

The 4 V rms output voltage of the new JAWS system has allowed us to calibrate precision ac instruments on higher voltage ranges. Other applications require the ability of these 2 V JAWS chips to generate two separate independent arbitrary waveforms that each have an amplitude up to 1 V rms. For example, we have used these dual 1 V quantum-accurate signals for impedance metrology. The two independently programable JAWS signals are combined with a digital bridge to replace the transformer-based sources typically used in precision impedance bridges. The new JAWS-digital bridge impedance systems have simplified and improved the uncertainty of comparisons between arbitrary impedances [3]. Another new application for JAWS circuits is ac power metrology, where dual quantum-accurate programmable

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signals with defined harmonic content having specified amplitudes and phases will provide direct quantum-based reference signals for calibrating electric power meters [4].

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