Tests on waveform synthesis in a new cryocooler setup

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***Abstract* — A new experimental setup based on a two-stage cryocooler has been developed at INRIM for operation with Josephson arrays. Recently some parts of the setup have been upgraded in order to allow the synthesis of waveforms; in particular, a well suited rigid rf coaxial cable with bandwidth exceeding 30 GHz has been mounted. We describe preliminary results obtained in tests of waveform synthesis with pulse-driven Josephson arrays fabricated at PTB. Unipolar sinewaves at 1.25 kHz and amplitudes ranging up to tens of millivolts were generated. Results are then discussed in relation with the specific thermal issues posed by He-free cooling.**

***Index Terms* — Voltage standards, Josephson effect, Cryocooler.**

I. INTRODUCTION

Applying short pulses instead of the sinusoidal rf signal used in traditional voltage standards allows the generation of arbitrary waveforms with quantum accuracy in a wide frequency range.

In the Josephson Arbitrary Waveform Synthesizer (JAWS) the pulsed technique is used to synthesize voltage signals with very high spectral purity. Recently the synthesis of ac signals at 1 V level has been reported by some NMIs by connecting series of arrays operating in liquid helium [1],[2].

Operation of Josephson standards inside a cryocooler is interesting to simplify their use, allowing more laboratories to perform ultimate accuracy calibrations. Yet, thermalization problems cooling are challenging.

Pulsed standards are a particularly interesting field of application of cryocoolers because of the expected impact in metrology of voltage standards approaching radio frequencies. The accuracy, when the quantum-standard signal frequency is increased, is ultimately limited by the loading effect of cables. Compact cryocoolers offer the opportunity to reduce the cable length and to overcome frequency-related limitations.

We developed a cryocooler-based Josephson system that can be operated both with programmable and pulse-driven standards.

In particular, to overcome undesirable thermal links, a special stainless steel coaxial cable is employed for pulse transmission, that, owing to the reduced thermal conduction of the material, can be shorter than in liquid helium probes nearly by a factor of two. We expect to improve the transmission of the quantum voltage signals from the chip to the output by substituting the transmission line with a second stainless steel cable. Preliminary tests in cooperation with Physikalisch-Technische Bundesanstalt (PTB) were performed with INRIM's cryocooler setup to investigate the pulse-driven technique for synthesis of waveforms at different amplitudes and how the spectral purity is influenced by the heat exchange when the array is simultaneously biased and irradiated with a stream of short current pulses. Series arrays fabricated at PTB were used to generate unipolar sinusoidal waveforms. Our JAWS samples consist of two arrays, with 4000 junctions each, fabricated on a 10 mm × 10 mm silicon chip.

II. CRYOGENICS AND MEASUREMENT SETUP

This section summarizes the relevant properties of the cooling and measurement apparatuses. Detailed descriptions have been already published [3].

Measurements were performed with a GM closed-cycle refrigerator, with an additional disk (coldplate) on top of cold finger, containing inside a thermometer and a heater for temperature monitoring and control. A second thermometer close to the chip was used to better estimate the array temperature. Since the chip is in vacuum, specific requirements are needed to maintain the proper temperature, minimizing the effects of the heat transmitted by measurement wires as well as heat generated by dc and ac bias electrical power.

We designed a new sample holder, made in Oxygen-free (OFHC) copper. To guarantee a good thermal contact between the chip and the coldplate, a special aluminum (Ergal) spring was used. Electrical insulation is kept by interposing a thin sapphire substrate between copper and chip, without a substantial reduction of thermal conduction.

III. ARRAY TECHNOLOGY AND CONFIGURATION

The work presented here uses arrays of Josephson junctions realized by PTB with Nb_xSi_{1-x} as barrier material, in order to achieve higher characteristic frequencies and lower current densities (20-30 kA/cm^2) [4]. Junctions are arranged in double stacks and are embedded into the center line of a 50 Ω coplanar-wave-guide (CPW) which ensures a suitable propagation of pulses.

The JAWS chip was mounted for He operation onto a chip carrier 23 mm × 40 mm made of Rogers RO3006. Two conducting CPW paths made of copper with a 2 µm gold layer on top (without nickel) are used for pulse transmission to the arrays.

The CPW lines of this carrier are connected to two PCB-SMA launchers for connection to coaxial cables [4].

III. MEASUREMENTS AND RESULTS

The array we used has a “distributed” structure, thus requires a resistive termination to avoid reflections. To avert any common mode voltage on resistor, the “ac coupling” technique was used [5][6][7]. The Pulse Pattern Generator, delivering unipolar non-return-to-zero pulses, was then connected using a dc block that removes the common mode signal at the array output. Sigma-delta codes were provided by PTB.

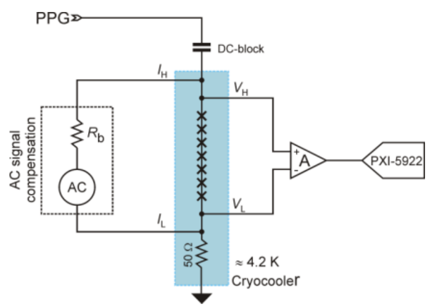

Fig. 1. Measurement circuit schematics

The output voltage of the Josephson array was observed and measured with a compact wideband digital modular system for dynamic measurement with fast frame rate [8], reconfigured for this experiment. Two mains-supplied high precision flexible resolution ac-coupled digitizers are connected in parallel and digitize simultaneously the waveform synthesized by the Josephson array (Fig. 1). One of the digitizers is configured for spectral measurement and the second one performs rms voltage measurements. To avoid ground loops, a low noise differential preamplifier was inserted between the JAWS output and the inputs of the digitizers. The amplifier gain was set to 1 and its distortion is better than 80 dB.

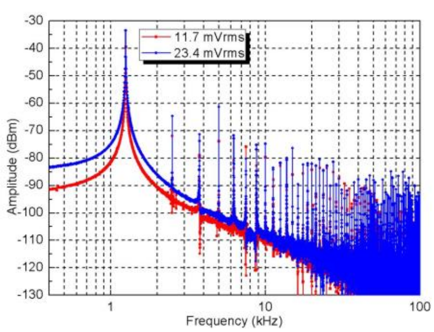

Fig. 2. Observed FFT spectra of two unipolar sine waves at 1.25 kHz and at 11.7 and 23.4 mV, respectively

We preliminary observed FFT spectra of unipolar sine waves at 1.25 kHz and amplitudes from 4.3 mV to 23.4 mV, i.e. from 15% to 80% of the sigma-delta code amplitude (two of them are shown in Fig. 2). The PPG clock frequency was 10 GHz. The compensation was provided by an additional ac synthesizer locked to the 10 MHz clock reference (see Fig. 1 for details). System tuning for optimal operating margins has been performed by observing the frequency spectrum at temperatures around 4.8 K, due to a temporary failure of a thermal link. The critical current was consequently reduced from 4.6 mA down to 2.6 mA, hence the JAWS array was not completely on-margins. Due to non-optimized experimental setup the frequency spectrum contains a lot of distortion tones. We suppose that there was still a ground problem in the setup.

VI. CONCLUSION

Preliminary tests of JAWS synthesis with a new cryocooler setup demonstrate generation of quantum ac voltages. Work is in progress to optimize operating parameters and, in particular, to bring the chip temperature to 4.2 K for improved operating margins and purity. Further details of the setup and more results will be presented at the conference.

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