Wideband digital modular system for dynamic characterization of PJVS

B. Trinchera, A. Sosso, U. Pogliano, V. Lacquaniti, E. Monticone, M. Fretto, R. Rocci, L. Roncaglione Tet, and D. Serazio

INRiM – Istituto Nazionale di Ricerca Metrologica, Strada delle Cacce 91, 10135 – Turin, Italy
b.trinchera@inrim.it

***Abstract* — This work deals with the use of high precision digital modular systems, employed towards a wideband chassis, for use with PJVS devices. A key feature of digital modular systems lies on their fast software reconfigurability, exploited to better adapt characteristics as well as performances of different boards (e.g., DACs, ADCs, timing and synchronization) to a specific experimental setup. A compact and modular wideband measurement system suitable to interact dynamically with series array of Josephson junctions is developed. Synchronous digital modules for digital synthesis of isofrequential LF triangular and RF rectangular patterns and precise sampling are used for real-time characterization of sections of a PJVS chip, which operates in a two-stage (4 K) cryocooler system. A suitable synchronous program has been developed and new algorithms are being tested for synthesis of arbitrary LF quantum waveforms, that will be used for direct traceability of digital systems .**

***Index Terms* — Digital-analog conversion, signal synthesis, sampling methods, Josephson junctions.**

I. Introduction

Inverse ac Josephson effect [1] is a widespread macroscopic quantum phenomenon used in most National Metrological Institutes (NMIs) and industrial laboratories for linking the volt to fundamental constants of nature. This has allowed the realization of conventional DC quantum voltage standards, up to 10 V level, with uncertainty ranging between 10^{-9} and 10^{-11}. Over the last two decades, series arrays of Josephson junctions [2] with nonhysteretic single-valued current-voltage behavior have been employed for the design and realization of suitable Josephson voltage standards to be used as a programmable dc voltage source and for the synthesis of alternating and time-varying quantum waveforms.

Several efforts on improvement of quantum voltage sources and on their direct use to ensure traceability of most precision digital systems are widely addressed[*] in [3]. However, to be operated as quantum voltage synthesizers, the series array of Josephson junctions must be sufficiently well-characterized.

A new wideband digital system, fully reconfigurable via software, is being developed at INRiM for use with series array of Josephson junctions operating in a cryocooler system. As first application, the system performs real time characterization of 1 V binary-divided overdamped superconductor/normal-insulator/superconductor (SNIS) Josephson junctions [4] and will also be used with pulse driven arrays. Dynamic *I-V* characteristic are recorded under different conditions (e.g. temperature and microwave power). Testing of single sections of a PJVS in the RF domain is performed by means of a differential RF-DAC and suitable balanced transmission lines are employed for this purpose.

By reconfiguring the system, LF arbitrary quantum waveforms may be synthesized and used for direct traceability of precision digitizers, which are widely employed in modern designing of wideband systems (for example, for power and energy [5]).

II. Description of the Experimetal Setup

A simplified diagram of the experimental setup employed (modular electronic control at room temperature, the cryogenic setup and connections to the PJVS chip) is shown in Fig.1. A novel chip carrier package has been designed [6], to improve and ensure uniform temperature distribution, when the PJVS chip is fitted in a two-stage cryocooler[†].

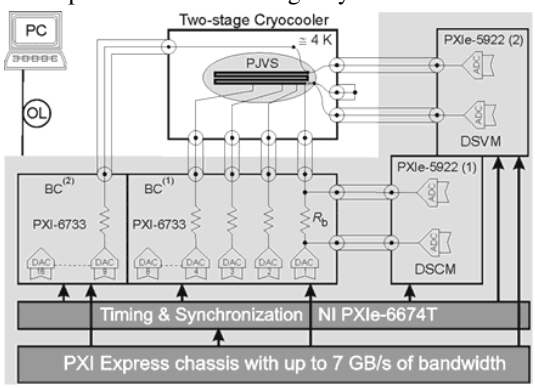

Fig. 1. Simplified schematic diagram of the experimental setup employed for the characterization of PJVS devices operating in a two stage cryocooler. For simplicity the microwave setup has been left out.

A. Wideband digital systems

A commercial PXI-express wideband chassis[‡] is equipped with several precision digital boards and a control software has been written in NI-LabWindows™/CVI. For real time characterization of PJVS devices the LF-DAC[§] is configured as an unbalanced polyphase arbitrary generator for direct synthesis of the biasing currents ($BC^{(1)}$); isofrequential LF patterns of triangular waveforms are used for this purpose.

[*] Part of this work is jointly funded by EMRP JRP SIB59 Q-WAVE.

[†] Two – stage Gifford-McMahon cryocooler system (≈ 4K).
[‡] NI PXIe – 1082 8 slot wideband chassis optically isolated from PC.
[§] NI PXI – 6733: 16–bit LF analog output with 1MHz of update frequency.

The effective number of isofrequential analog outputs may be increased up to 16 by adding a second LF-DAC board (BC$^{(2)}$). A synchronous four channel digitizing[**] system, with sampling frequency up to 15 MS/s, is employed for current and voltage waveform recording. Two synchronized ADC boards are used for this purpose. The first one is configured as a differential sampling current monitor (DSCM), the second one as a differential sampling voltage monitor (DSVM). A precision timing[††] and synchronization module ensures direct synchronization of DAC and ADC boards.

Preliminary characterization of a PJVS quantum device and transmission lines in the RF domain is performed by means of a high speed RF-DAC[‡‡], which is provided with a complementary current output signal. It is configured as balanced bias current generator for the synthesis of wideband current pulses.

B. Transmission lines

For LF dynamic characterization of PJVS devices single-ended transmission lines are used to connect the digital boards, installed in the same chassis, and the input flange of the crycooler, equipped with a suitable high vacuum connector. The length is kept as short as possible and coaxial cables of effective length of about 50 cm are used. Instead, for RF polarizing of single sections of PJVS, an arrangement similar to that employed in balanced transmission lines is adopted. Flexible coaxial cables with bandwidth up to 20 GHz are used and further experiments are in progress.

C. System design software

The control program has been written in NI LabWindows™/CVI. Under real-time constraints, concepts such as multithreading and parallel computing architecture are fundamental and fairly straightforward to be implemented when multi pattern signals are simultaneously generated and acquired. In order to avoid heavy usage of local PC memory and CPU resources, efforts are in progress towards the implementation of a numerical accelerator sub-system, based on a GPU computation board, in CVI environment.

III. TESTS AND RESULTS

Specific experiments were carried out in order to test the functionality of the digital system and for dynamic characterization of different sections of a 1-V SNIS PJVS device, with and without microwave irradiation. Binary-divided series arrays containing up to 8192 Josephson junctions were characterized. Fig.2 shows several *I-V* characteristics measured on different sections of a PJVS under microwave radiation. As it can be seen from the current margins reported in the enlarged inset graph of Fig. 2, its amplitude decreases, most likely due to thermal effects [6], in sections containing a large number of Josephson junctions.

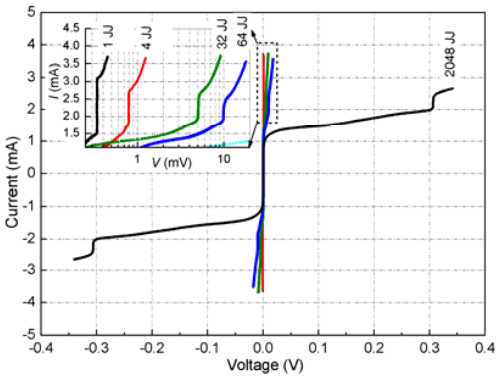

Fig. 2. *I-V* characteristic of sections of a 1-V PJVS based on SNIS technology operating in a cryocooler system. Characteristic voltage $V_c = n{\cdot}f_{\mu W}{\cdot}h/2e \approx 150\ \mu V$ for n = 1 step and $f_{\mu W} \approx 70$ GHz.

VI. CONCLUSIONS AND FUTURE WORK

A compact and modular digital system for use with programmable quantum voltage standards is proposed. It allows quick and wideband characterizations of PJVS devices and transmission lines. Sub-sections of a 1 V SNIS PJVS chip containing up to 8192 junctions have been dynamically characterized. Further tests, by using balanced current pulses, will be performed by means of a RF-DAC for fast polarization of PJVS and system estimation bandwidth. A new algorithm for synthesis of LF quantum waveforms, with fast loading and updating of arbitrary waveform pattern, is being developed and further details and experimental results will be given at the CPEM conference.

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[**] NI PXI – 5922: 16 to 24 bit flexible resolution digitizer.
[††] NI PXIe – 6674T: Timing and multichassis synchronization module.
[‡‡] NI PXIe – 5450: 400 MS/s dual channel, 16-bit I/Q signal generator.
The identification of the reconfigurable digital platform employed does not imply recommendation or endorsement by INRiM, nor does it imply that the digital modules used are necessary the best ones available on the market for this purpose.