Fast Synchronous AC-DC Transfer Measurements with a Programmable Josephson AC Voltage Standard

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***Abstract* — This paper presents the setup for investigating INMETRO´s programmable ac voltage standard with thermal converters. Of primary interest is the validation of differential ac voltage calibrations of the Josephson system with thermal converters and their calibration against the quantum system. Proposals for attaining these goals are presented.**

***Index Terms* — Ac voltage, ac-dc transfer, digital signal processing, Josephson, measurement standards, sampling technique.**

I. Introduction

After developing an automated ac voltage calibration system based on a programmable Josephson ac voltage standard (PJVS) [1] we seek its validation with the help of thermal converters (TCs). Three main tasks are deemed fundamental and are listed in order of importance as follows: (a) The validation of ac voltage calibrations from differential voltage measurements done with the PJVS, (b) the calibration of ac-dc transfer errors of thermal converters and finally, (c) the determination of the measurement limitations of the PJVS by measuring the energy content or rms of a PJVS waveform. The last task has been extensively investigated by other researchers, who devoted diligent efforts on painstaking evaluations of transient effects on the root-mean-square (rms) value of a PJVS waveform. Only approximate solutions have been found to this problem [2]. The reason – according to author´s interpretation – lays in the difficulty to link the macroscopic definition of the rms with particular microscopic characteristics of the actual signals under nonstationary und not fully predictable step transitions. The measurement of differential ac voltages seems to be the best approach to calibrate ac signals without the need to consider step transitions of the PJVS. The first two tasks (a) and (b) are thus the focus of the work.

II. Measurement Setup and PJVS Validation

Fig. 1 shows the measurement setup. The gray shaded area represents the PJVS calibration system as described in [1]. The ac source is continuously calibrated against the PJVS as described [1]. For higher voltages, an inductive voltage divider (IVD) can be used to extend the range of PJVS ac calibrations by measuring at its secondary and by determining $kv_{AC}(t)$, for k (less than 1) being the ration constant of the IVD. A dc calibrator with known calibration errors is used for ac-dc transfer measurements, which must occur synchronously with the zero crossings of the ac signal (controlled by hardware, i.e., by the synchronous comparator in the insert of the optical switch in Fig. 1) in order to speed-up measurements as described by the author in [3]. Obviously, the dc reference can equally be derived from the PJVS eliminating the need of a dc calibrator.

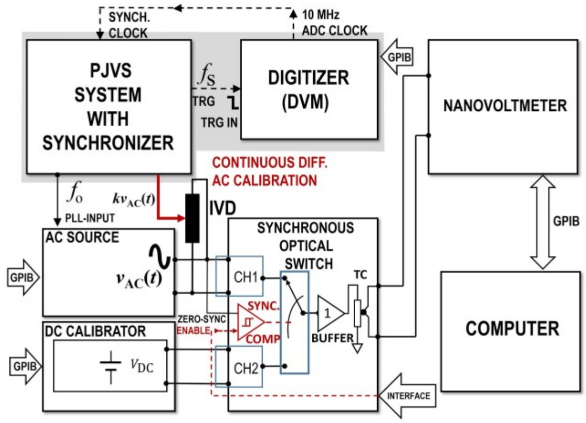

Fig. 1. Diagram of the measurement setup.

For lower voltages, e.g. smaller than 10 V (peak), a buffer provides impedance matching, which may be substituted by a series calculable resistor for higher voltages. We identified eight circuit topologies for this buffer [4].

The sequence of measurements are AC, +DC, AC, -DC and so on, as known in ac-dc transfer measurements. A nanovoltmeter measures the output of a multi-junction TC. The PJVS´ ac voltage determinations of $v_{AC}(t)$ via differential measurements are compared with the calibrator´s dc value adjusted by the computer as described in [3], what allows validation of the ac voltage calibrations as in [1] with a TC.

The optically isolated synchronous switch has suffered further refinements for higher voltages, since the publication of [3]. It comprises an arrangement of two n-channel metal oxide semiconductor (N-MOS) transistors Q_1 and Q_2, driven by an in-house built fast optical driver. Fig. 2 shows the fast bipolar bidirectional switch, which operates at either dc or ac. Its turn-on and –off switching times range from 10 ns to 100 ns depending on the N-MOS chosen and on a given load.

The fast optical driver is a complex arrangement of discrete transistors, which are current controlled for the utmost speed, possessing its own isolated dc supply referenced to the source leads of Q_1 and Q_2. It allows +15 V for turning-on and -15 V for turning-off to be applied to the gates of Q_1 and Q_2 within some nanoseconds. In conduction, one of the transistors

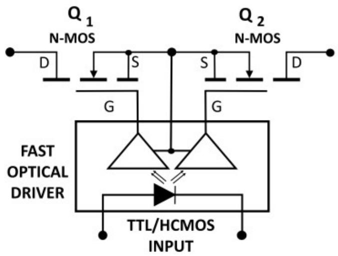

Fig. 2. An ultra-fast N-MOS based and optically controlled switch with high voltage isolation between drains and controlling leads was built. It is able to switch small voltages as some millivolts up to hundreds of volt (either ac or dc). Switching speed attained was smaller than 100 ns depending on the transistors used (see text). A second switch is tied to a dc source with drivers synchronized.

operates in reverse mode, so that the drain-source voltage is dependent on the load current (in this case the TC) and operating voltage. In order to eliminate the effects of residual channel voltages that could slightly impair ac-dc transfer measurements, a classical mechanical relay (not shown in Fig. 2) is operated in parallel shunting both drains. This relay closes last and open first before the MOS-switch is triggered by the driver. A dedicated digital circuitry with an interface to a computer takes control over the switch and precludes short-circuit between ac and dc sources to occur, when the switching command is sent by the controlling computer (a personal computer). The MOS-switches thus guarantee by its high speed that the thermal converter never experiences pronounced heat losses during switching from ac to dc and vice-versa as detailed in [3], keeping it thermodynamically in equilibrium what speeds up ac-dc transfer measurements enormously. Investigations are in course with fast electronics to verify its performance, frequency range and other issues. These are to be detailed in the extended paper.

III. Thermal Converter Characterization

Relying on the quantum accuracy of the PJVS, a thermal converter can be fully characterized, even at very low frequencies (less than 10 Hz) where other errors due to nonlinear heat transfer processes take place. Besides that, the power dependence of a TC can be measured. These characterizations are expected to be valid up to some kHz, since the PJVS does not allow audio-frequency signals to be synthesized. Beyond this limit, either theoretical evaluations or comparisons shall guarantee ac-dc transfer measurements. Nevertheless, the authors expect that the measurement setup of Fig. 1 be a valuable aid also towards developing new thermal converters.

IV. PJVS Evaluation Against TCs

Investigations done by other researches are expected to remain valid also for INMETRO´s PJVS system, so that a verification of those findings is of interest to us to infer on the proper operation of our PJVS system. These measurements will also be thus conducted.

Worth mentioning, our PJVS calibration system was intentionally synchronized to the internal 10 MHz clock reference of a digitizer. The reason for doing so is to avoid introducing more jitter into the digitizer and to allow some freedom in varying the update rate of our DACs biasing the Josephson arrays. With the help of a direct-digital-synthesizer, the PJVS synchronization with other sources is also possible, even if these do not possess any synchronization feature. This could be, e.g., a special R-C ultra-pure sine generator of highest stability and expected signal purity bearing the -160 dB to be calibrated directly with the PJVS. This would employ special equations for synchronization to allow coherent sampling. Equations for synchronizing adaptively analog-to-digital converters were presented in [5] and to synchronize their digital-to-analog counterparts in [1] (patent pending). Both algorithms may be employed in order to tackle difficult synchronization issues.

VI. Conclusion

A system for doing ac-dc transfer measurement investigations of a PJVS was shown. This system shall deliver validation of our PJVS system and allow TC to be calibrated as well. In the extended paper the focus will be on measurement results in regard to the tree main tasks mentioned.

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