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Trilateral comparison among digital and Josephson impedance bridges / Marzano, Martina; Ortolano, Massimo; Overney, Frédéric; Eichenberger, Ali L.; Kucera, Jan; D'Elia, Vincenzo; Bartova, Lucie; Medved, Juan; Callegaro, Luca. - ELETTRONICO. - (2024), pp. 1-2. (Intervento presentato al convegno Conference on Precision Electromagnetic Measurements (CPEM) tenutosi a Denver, CO (USA) nel 08-12 July 2024) [10.1109/cpem61406.2024.10646159].

Availability:

This version is available at: 11583/2992335 since: 2024-09-10T07:46:22Z

Publisher:

IEEE

Published

DOI:10.1109/cpem61406.2024.10646159

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Trilateral Comparison Among Digital and Josephson Impedance Bridges

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Abstract—In this work, we present the results of an onsite trilateral comparison between a dual Josephson impedance bridge developed by METAS and the electronic fully-digital impedance bridges developed by CMI and INRIM-POLITO. The target accuracies of the bridges are at the 10^{-8} level for the former and at the 10^{-7} for the latter. Here we report the results of the calibration of a 10 nF capacitance standard against a 12.9 k Ω calculable resistance standard at 1233 Hz, conditions suitable for the primary direct realization of the impedance units ohm and farad from AC quantum Hall resistance standards or from AC/DC calculable transfer resistance standards calibrated against DC quantum Hall resistance standards.

Index Terms—Metrology, calibration, impedance measurement, bridge circuits, Josephson effect

I. INTRODUCTION

Dual Josephson impedance bridges (DJIBs) and electronic fully-digital impedance bridges (FDIBs) have emerged in recent years as devices suitable for the primary direct realization of the impedance units ohm and farad from AC quantum Hall resistance (QHR) standards or from AC/DC calculable transfer resistance standards calibrated against DC QHR standards. The target accuracy for DJIBs is at the 10^{-9} to 10^{-8} level, whereas that for FDIBs is at the 10^{-8} to 10^{-7} level. In 2020, INRIM, METAS, PTB and POLITO started the project EURAMET TC-EM 1501, *Technical assessment of novel digital impedance bridges* [1], with the aim of performing comparisons among impedance bridges under development. The project is being coordinated by INRIM, and CMI joined it at the end of 2023.

A first round of comparisons took place from September to November 2021 when the INRIM-POLITO FDIB was moved to Braunschweig to be compared with the PTB DJIB. The results of this first round were published in [2]. A second round of comparisons took place in 2023 in Bern, where the INRIM-POLITO FDIB (from October to December) and the CMI FDIB (mid October) were moved to and compared with the METAS DJIB.

II. PARTICIPATING IMPEDANCE BRIDGES

An impedance bridge determines the ratio of two impedance standards. The DJIB and the two FDIBs participating in this comparison are four-terminal-pair (4TP) sourcing bridges, where the impedance ratio is determined from a reference voltage ratio generated by a multiphase two-channel source, and the impedance standards are defined as 4TP standards [3]. In a DJIB, the source is a dual Josephson arbitrary waveform

synthesizer (JAWS); in a FDIB, the source is an electronic digital synthesizer. These bridges can compare like impedances (e.g. $R : R$ or $C : C$) or unlike impedances (e.g. $R : C$ or $R : L$), determining magnitude and argument (phase) of the ratio. The 4TP definition of the impedances is realized by a number of auxiliary sources, injection and detection transformers, and detectors. A bridge is balanced when both the mean (main balance) and the difference (Kelvin balance) of the voltages at the low potential ports of the impedances are zero, and when the currents at the high potential ports are zero (current balances). To compensate the possible asymmetries in the bridge networks, the measurements are performed in two successive configurations, typically labelled *forward* and *reverse*, differing by the exchange of the impedances. Fig. 1 shows a picture of the three bridges in the METAS laboratory.

The CMI FDIB is based on the reconfigurable bridge [4], where the reference ratio of the bridge is formed by the ultra-stable two-channel generator SWG [5]. The 4TP definition of the impedances under comparison is fulfilled by means of additional sources and injection circuit. In the 1:1 ratio mode, a two-step measurement is performed, where rebalancing in the second step is done with an additional injection circuit situated in one of potential arms. The full automation of the bridge balancing and reversing of sources is performed with the second generation of coaxial switches based on [6]. High stability of channel outputs and low crosstalk between two reference channels (both around 10^{-8} V/V) ensure negligible influence of channel swapping and phase rotation of one



Fig. 1. METAS laboratory with the authors and the three installed bridges: from left to right, METAS DJIB, CMI FDIB, INRIM-POLITO FDIB.

