Publishable JRP Summary for JRP SIB53 AIM QuTE Automated impedance metrology extending the quantum toolbox for electricity

Background

Currently, impedance standards are maintained by numerous artefacts to cover a wide range of values. The chain of calibrations needed for the generation of an impedance scale and the link between different impedance types – resistance, capacitance and inductance – is achieved, at the NMI level, with transformer based coaxial bridges. All these measurements are performed at a single frequency and the bridge needs to be recalibrated for each decade of capacitance. In their classical implementations, coaxial bridges use a number of fixed and variable transformers and inductive voltage dividers and their complexity requires a highly skilled operator to operate and balance these coaxial bridges. Attempts to automate these bridges invariably result in larger uncertainties due to the inherent limitations introduced by controlling these variable devices remotely.

This JRP will advance beyond this state of the art in multiple areas. Firstly, it will extend Josephson impedance bridges e.g. to measurements:

- along the axes of the complex plane of impedance (*R:R, C:C* and *L:L*) – arbitrary ratios of like impedances –,
- between the axes – quadrature bridges,
- and at arbitrary phase angle.

Secondly, fully digital bridges will be developed to reduce the operator workload imposed for the realisation of the impedance scales and for calibrations. The target level of uncertainty for these fully digital bridges is parts in 10^7.

Both novel types of impedance bridges can measure arbitrary ratios with the same precision and also independently of the phase angle. The blue lines in figure 1 show the frequency independent uncertainties that should be available at the end of the JRP when using Josephson or fully digital bridges (dotted and solid lines, respectively). Today's state of the art uncertainties are indicated in red.

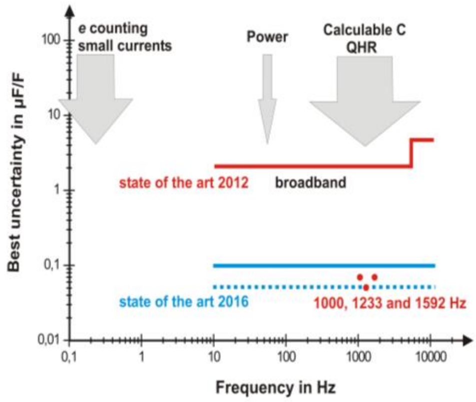

Figure 1. Uncertainty as a function of frequency for the calibration of a 100 pF capacitance standard.

Finally, the infrastructure for impedance will be improved with the active and passive impedance standards manufactured in the JRP. Sub-pF standards are required to establish traceability for this end of the impedance scales, where there are none at the moment. In addition, an electronic impedance simulator will cover a very large region of the complex impedance plane and significantly reduce the number of standards that are required to link the traceability of top level calibration laboratories to NMIs.

Need for the project

Impedance is used directly in some applications, such as the manufacture of passive electronic components and indirectly to measure a huge number of other magnitudes, such as resistance based temperature

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metrology, electrochemical impedance spectroscopy for the analysis of battery electrolytes, calibration of dosimeters for ionizing radiation, sound and vibration instrumentation, and commercial sensors e.g. touchscreens or fuel gauges. Both “end users” of impedance measurements and instrument manufacturers have identified areas in need of improvement that will be addressed in this JRP.

Presently, the lowest uncertainties for impedance calibrations are restricted to previously defined ratios and phase angles. An artist’s impression of the best possible accuracies that can be achieved, is displayed in figure 2. For clarity, only the sub-plane between the axes for capacitance at a fixed frequency and resistance are shown. The values that can be measured with high accuracy (parts in 10^8) are the decadic values and the QHR values.

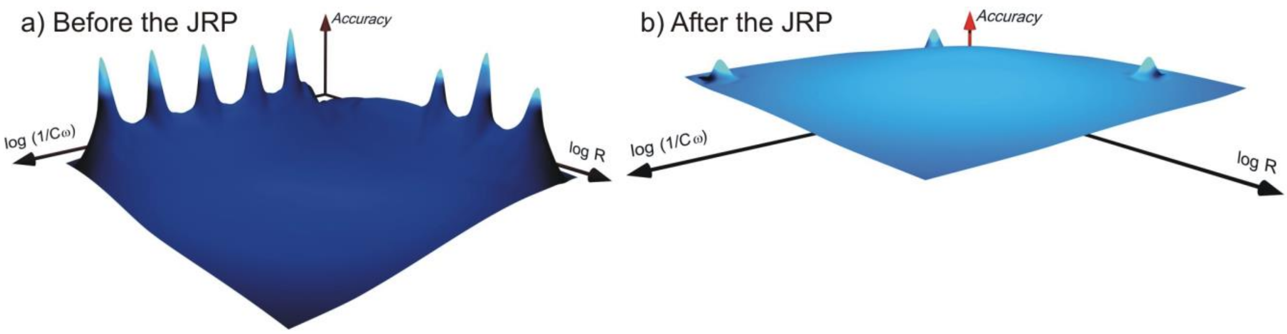

Figure 2. Artist's impression of the best accuracy attainable for a region of the impedance complex plane.

In the JRP, a novel programmable impedance simulator will be built with the potential of substituting a large number of standards. The suitability for this will be established during onsite testing at a commercial calibration laboratory, however the impedance simulator is expected to greatly simplify testing and calibrating impedance measurement instruments.

Scientific and technical objectives

The overall aim of this JRP is to provide the improved tools and methods needed to establish the impedance scale. The aim is to meet user requirements for reliable impedance measurements in the whole complex plane, in the frequency range between 10 Hz and 20 kHz.

The JRP addresses the following scientific and technical objectives:

- To realise Josephson based impedance bridges for arbitrary ratios of like impedances (*R:R, C:C* and possibly *L:L*), and 1:1 ratios for quadrature measurements. By the end of the project, four partner NMIs and a collaborator will operate Josephson impedance bridges.
- To develop automated impedance ratio bridges and perform proof-of-concept tests at an uncertainty level of 10^{-7} covering the frequency range from 10 Hz to 20 kHz.
- To extend the impedance scales to intermediate values along the axes (*R*, *L* and *C*), to intermediate phase angles and towards values demanded by nanotechnology (capacitances below fF), and to develop the corresponding standards.

Expected results and potential impact

The direct impact of the JRP will be predominantly on traceability and NMI capabilities. New routes will be established where there are none at the moment (for impedance values commonplace in nanotechnology). The extension of NMI calibration capabilities to intermediate phase angles will also allow confirmation of industrial calibration of standards. Automated impedance bridges for unprecedented accuracies will also reduce the costs of calibrations. At least nine NMIs will operate automated bridges by the end of the JRP; five of them based on Josephson arrays. Four JRP-Partners will develop and test fully digital bridges that also operate over a comparable frequency range and without the need for a highly skilled operator.

Additional potential for reductions in the complexity and costs associated with today’s maintenance of the impedance scales will be achieved through the programmable impedance simulator developed in this JRP. Furthermore, the new, broadband impedance bridges from this JRP will enable a more precise understanding of the reported difference in value of capacitance standards between DC and AC, with a direct impact in the “mise en pratique” for capacitance and current. The reduction in uncertainties for the measurement of capacitance at low frequencies (< 500 Hz) that will be achieved by the JRP, will also improve the present extrapolation to a “DC capacitance”.

The JRP-Consortium has identified twenty four interested stakeholders that are distributed in Europe, North America and Australasia: fourteen companies, four research institutions and six NMIs. Manufacturers of passive electronic components, instrumentation manufacturers for impedance measuring equipment and their users will also benefit from the automated operation of the bridges developed in the JRP. A stakeholder committee has been set up and is open to all interested parties.

So far the JRP has made a good scientific progress in the first six months. A cryocooler for a Josephson impedance bridge with two Josephson series arrays has been tested successfully at MIKES. SP has also tested all the equipment required for its Josephson impedance bridge. CMI, INRIM, METAS, MIKES, Trescal, REG(SUT) and REG(UZG) have written the specifications of the two sets of digital signal sources (DSS) that will be built in the JRP. The target is to improve commercially available DSSs in the context of digital impedance bridges. Extensive testing of commercially available DSSs was performed at MIKES, INRIM, METAS and as part of the guestworking periods of REG(SUT). Trescal also visited METAS to take part in these measurements. First experiments have been performed at INRIM on a three-arm, two terminal-pair current comparator digitally assisted bridge with impedances in the 10-100 kΩ range at 1592 Hz. Last but not least, the JRP-Partners agreed on the nominal values of the passive impedance standards with phase angles of ±30º and ±60º that will be built by TUBITAK.

In the first six months, two presentations at conferences; the 16th International Congress of Metrology 2013 and 10th Seminario Internacional de Metrología Eléctrica (SEMETRO) were given and one article has been published. The public part of the JRP website is also being set up for end-users to access information on the JRP.

JRP start date and duration:	1 June 2013, 36 months
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