Title: Automated impedance metrology extending the quantum toolbox for electricity

Abstract

Impedance is central in electrical metrology and also in many other disciplines that use impedance changes in sensors for their measurements. The present dissemination of the impedance units and the associated metrology infrastructure is based around manually operated coaxial bridges that can be used over a limited frequency range. Applying new techniques, automated impedance bridges can be developed that would avoid the previously inevitable penalty in uncertainty. In addition, the lower frequency boundary for these high precision measurements can be reduced. The same techniques enable overcoming the present limitations in phase angles and demand the development of suitable standards with improved uncertainties. The new bridge technologies developed can be exploited to improve the metrology infrastructure for the dissemination of a range of units including the ohm, farad and henry.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP Outline 2008, section on “Grand Challenges” related to Health, New Technologies & Fundamental Metrology on pages 10, 11 and 32.

Keywords

Electrical impedance scales, capacitance, impedance bridges, quantum Hall effect, metrology infrastructure, quantum standards, traceability, dissemination of units.

Background to the Metrological Challenges

Most electrical metrology starts from the quantum references that are well established for DC voltage and resistance. Deriving AC quantities (capacitance, inductance, AC resistance etc) from the DC starting point at the highest level is not trivial. Dissemination of the AC ohm, farad and henry at the primary level is presently based on manually operated impedance bridges that use fixed and variable transformers. The uncertainties, as can be seen on the BIPM database for calibration and measurement capabilities (CMCs), range from parts in 10^8 to parts in 10^6 and cover the frequency range from 500 Hz to 10 kHz. The complexity of the bridges demands a highly skilled operator for balancing them. Moreover, the bridges need to be recalibrated at each frequency of operation. There are several new techniques that may allow more modern replacements of the manual coaxial bridges still required for top level impedance measurements. The application of AC Josephson sources to impedance work is one possibility that shows promise [1] but needs further development. Modern digital electronic techniques may also play a role in this area.

An additional unsatisfactory situation was highlighted at the last Conference on Precision Electromagnetic Measurements in Daejeon, in June 2010, by researchers from NPL, PTB and BIPM who reported a discrepancy of parts in 10^6 between the DC capacitance and the value extrapolated from AC measurements for a number of standards used at NMIs. Their measurements illustrate a gap in capacitance measurements between DC and 50 Hz, which expands to the range DC to 500 Hz when the acceptable uncertainty is lowered to parts in 10^8. This discrepancy impacts two recommendations for the “mise en pratique” reflected in the CCEM/09-05 document [2] for current and for capacitance: 1. Recommendation (c) where a DC capacitance is used for the realisation of the ampere, and 2. the recommendations for the realisation of the farad based on capacitance measurements at AC(options (a) and (b)) or on a DC measurement (option c)).

Recent work on impedance standards has extended its operation to AC and provided traceability for “a set of capacitance standards with decade nominal values from 10 nF to 10 pF with a relative uncertainty of only 1.2×10^{-8} ($k = 2$)” [3]. Potential for significant improvement in the “established state of the art” for impedance metrology has been shown in the iMERA-Plus project T4 J03 JOSY. [4]. The properties of the quantum derived voltage sources were combined into an intrinsically referenced measuring method that does not require calibration and allows removal of all fixed or variable transformers in the impedance bridge. In addition, the following significant results were also achieved in this proof-of-principle experiment: an uncertainty of a the few parts in 10^8 level was extended to lower frequencies, there was no need for recalibration at each frequency or signal level, the bridge could be operated in an almost completely automated manner and the low uncertainties are in principle not restricted to particular ratios.

These measurements provide only a single point on one of the axes of the impedance plane but open the possibility of being extended continuously along the axes of the complex plane of impedance –arbitrary ratios of like impedances–, to measurements between the axes –quadrature bridges– and possibly the intermediate regions –arbitrary phase angles.

Scientific and Technological Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the JRP-Protocol.

The focus of this SRT is to provide the tools and methods needed to establish the impedance scale based on quantum standards. The aim is to meet user requirements for reliable impedance measurements in the whole complex plane, up to a frequency of 20 kHz.

The specific objectives are

1. Realisation of 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;
2. Realisation of automated impedance ratio bridges at an uncertainty below 0.1 ppm, covering a frequency range from 10 Hz to 20 kHz;
3. Improved metrology infrastructure for the dissemination of the ohm, farad and henry, by establishing calibration capabilities for all values along the impedance scales and arbitrary phase angles.

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. To enhance the impact of the research work, the involvement of the larger community of metrology R&D resources outside Europe is recommended.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this. Reference should be made to the iMERA-Plus project T4 J03 JOSY.

The total eligible cost of any proposal received for this SRT is expected to be around the 2.7 M€ guideline for proposals in this call.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community. This may be through the inclusion of unfunded JRP partners or collaborators, or by including links to industrial/policy advisory committees, standards committees or other bodies. Evidence of support from the “end user” community (eg letters of support) is encouraged.

You should detail other impacts of your proposed JRP as detailed in the document “Guide 4: Writing a Joint Research Project”

You should detail how your JRP results are going to:

- feed into the development of urgent documentary standards through appropriate standards bodies
- transfer knowledge to the instrumentation sector and other calibration laboratories,
- the European electrical measurement community

You should also detail how your approach to realising the objectives will further the aim of the EMRP to develop a coherent approach at the European level in the field of metrology. Specifically the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of Member States and countries associated with the Seventh Framework Programme whose metrology programmes are at an early stage of development to be increased
- outside researchers & research organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.

Additional information

The references were provided by PRT submitters; proposers should therefore establish the relevance of any references.

[1] 'The Josephson two-terminal-pair impedance bridge', J. Lee *et al*, Metrologia, Vol. 47(4), pp. 453-459, 2010

[2] http://www.bipm.org/cc/CCEM/Allowed/26/CCEM-09-05.pdf):

[3] Schurr, J., Bürkel, V., and Kibble, B. P., *Realizing the farad from two ac quantum Hall resistances*, Metrologia, 46, pp. 619-628, **2009**.

[4] Lee, J., Schurr, J., Nissilä, J., Palafox, L., and Behr, R., *The Josephson two-terminal-pair impedance bridge,* Metrologia, Vol. 47(4), pp. 453-459, **2010.**