**EMPIR Call 2020 – Fundamental, Industry and Normative**

Selected Research Topic number: **SRT-i28**
Version: 1.0

# Title: Metrology for broadband impedance: bridging the LF-HF gap


## Abstract

Traceability of impedance measurement above certain frequencies is challenging due to the lack of methods and standards in the frequency band from 1 MHz to 100 MHz (the "frequency gap"). There is a clear need to develop new methods for frequencies of 100 MHz and beyond with an accurate phase calibration. Established and growing markets like semiconductor testing, characterisation of low-loss materials, energy storage, capacitive sensors, MEMS testing, cell biology and diagnostics or even electrical grid communication will benefit from this innovation.



## Keywords

Electrical impedance, frequency gap, calibration, traceability, phase standards, quality factor, power-line communication.


## Background to the Metrological Challenges

The miniaturization of components and circuits increased the need for impedance measurements at higher frequencies. An example are high-quality capacitors that often exhibit excellent quality factors even above 100 MHz. Accurate phase measurement is at the heart of every impedance measurement. While separate phase measurement or calibration is typically a "byproduct" of an impedance measurement, new (e.g. sampling) techniques rely more or less on a direct phase measurement. As commercial or experimental phase standards are virtually non-existent in NMIs, the study and development of a phase standard for both generation and measurement is a cornerstone for further improvement and validation of new impedance measurement technologies in the frequency gap.

The impedance characterization of the low voltage grid is a pending task for the upcoming deployment of Power Line Communication (PLC) technologies for smart electrical grids, aiming at frequencies up to 30 MHz (current frequency range is up to 150 kHz). As the access impedance of the grid is a key factor for the performance of these technologies, the development of traceable measurement methodologies and calibration procedures, consistent coupling devices and robust, portable and accurate measurement systems that cover this wide frequency range are needed.

At low frequencies, accurate calibration of impedance standards is usually carried out with coaxial ac bridges: a quadrature bridge to link the resistance to the capacitance, a Maxwell–Wien or a resonance bridge to link the inductance to the capacitance, and ratio bridges to scale impedances of the same kind. These bridges provide the best accuracies: $10^{-6}$ for the calibration of inductance standards and $10^{-8}$ for the calibration of capacitance or resistance standards. However, these are time consuming to set up, tedious to operate, and usually limited to a narrow operating frequency range (usually around 1 kHz).

Within the project EMRP SIB53 AIM-QuTE, different measuring bridges mixing classical voltage or current transformers and analogue-to-digital components have been developed. They improved the traceability of impedance over the entire complex plane allowing the direct comparison of any pair of impedances regardless of their magnitude and phase. The working frequency of these new bridges is however still limited to about 20 kHz.

Due to the lack of impedance analysers in the 100 MHz range, Vector Network Analyzers (VNAs) are commonly used in this range. VNA impedance measurements require a previous VNA calibration with known reflection and transmission standards. The calibration occurs with air-dielectric line standards of different lengths. These measurements start at 500 MHz and go up to 110 GHz due to limitations of the maximal line length and diameter. However, the gap between DC and 500 MHz is bridged in VNA measurements by interpolation, a necessity because no resistive elements, calculable up to this frequency, are currently available.

A breadth of applications relies on impedance measurements in the frequency gap between 1 MHz and 100 MHz. Traceable and accurate calibration standards and methods applicable in this range are still missing.

## 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 protocol.

The JRP shall focus on the traceable impedance measurement methods for frequencies of 100 MHz and beyond with an accurate phase calibration.

The specific objectives are

1. To develop traceable methods (including finite element simulation) for the calibration of impedance measuring instruments at frequencies between 1 MHz and 100 MHz using calculable resistive and capacitive standards. The discontinuity in the uncertainty level that presently exists at the transition from the coaxial-bridge-based calibration method to the VNA-based method will be removed.
2. To develop phase standards for both generation and measurement, with target uncertainty below 1 µrad at low frequencies and below 5 mrad at 100 MHz.
3. To develop methods for on-site impedance measurements up to several tens of MHz, usable in harsh environments, in the low voltage power grid, as needed for power line communication purposes.
4. To facilitate knowledge transfer to other NMIs and engage with European instrument manufacturers for the development of innovative, high-accuracy impedance-measurement products. To facilitate the take up of the infrastructure developed in the project by the measurement supply chain, standards developing organisations (ISO, CEN) and end users in the electronic, energy and biomedical sectors.

Proposers shall give priority to work that meets documented industrial needs and include measures to support transfer into industry by cooperation and by standardisation. An active involvement of industrial stakeholders is expected in order to align the project with their needs – both through project steering boards and participation in the research activities.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of the EMRP projects ENG52 Smart Grid 2 and SIB53 AIM-QuTE and EMPIR projects 17RPT04 VersICaL and 18NRM05 SupraEMI and how their proposal will build on those

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.5 M€, and has defined an upper limit of 1.8 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 30 % of the total EU Contribution across all selected projects in this TP.

Any industrial partners that will receive significant benefit from the results of the proposed project are expected to be unfunded partners.

## Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the electronics, energy and biomedical sectors.

You should detail other impacts of your proposed JRP as specified in the document "Guide 4: Writing Joint Research Projects (JRPs)"

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. 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 EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

## Time-scale

The project should be of up to 3 years duration.