

Title: Advancing the European metrology for wideband AC voltage

Abstract

During recent years the performance of various measuring equipment for measurement of Alternating Current (AC) voltage at frequencies up to 100 MHz has been considerably improved. Due to the lack of improved calibration services in this field, the current European metrological capability lags behind the market needs and currently none of the European National Metrology Institutes (NMIs) has the full capability to calibrate this equipment. The novel wideband AC voltage measurement standards and sources will play a crucial role in transferring wideband AC voltage traceability from primary level to calibration laboratories and industry. Therefore, proposals addressing this topic should focus on to develop and validate the novel primary Radio Frequency to Direct Current (RF-DC) standards, to improve the measurement methods and setups by means of collaborative research in order to enhance the traceable calibration services in Europe in this field.

Keywords

AC voltage, RF-DC transfer, thermal voltage converter, matched system, mismatched system, wideband

Background to the Metrological Challenges

The increasing requirements for measurement of AC voltage in the frequency band above 1 MHz are coming from various sectors such as research, calibration laboratories, industry, healthcare and communication. Recent advancements in wideband measuring instruments, used in calibration laboratories and industry (such as wideband AC measurement standards and sources), have extended bandwidths to 50 MHz. High-speed digitizers further expand applications, but European metrology efforts lag behind the market needs due to insufficient calibration service development. In order to meet the requirements for the calibration of novel wideband equipment, the RF-DC standards, measurement methods and setups need to be improved.

The measurement of harmonics in power quality analysis for advanced smart electrical grids is extending to higher frequencies. The EMPIR project 15RPT04 TracePQM developed a traceable power quality measurement setup operating up to 1 MHz; and with EMPIR project 20FUN07 SuperQuant, research advanced to base AC voltage metrology on fundamental constants using quantum standards like JAWS (Josephson Arbitrary Waveform Synthesiser), which remain experimental above 1 MHz. Future efforts in AC voltage metrology at frequencies above 1 MHz will require verification and validation using alternative methods with sufficiently low uncertainties such as RF-DC based methods.

Today's AC voltage quantum standards provide calibrations only up to several kHz at 7 V, with systems for 100 kHz still in development and the 1 MHz to 100 MHz range remaining experimental. Linking AC voltage measurements in this range to the quantum SI requires alternative methods as well. Based on published Calibration and Measurement Capabilities (CMCs), none of the European NMIs is able to fully calibrate the key wideband measuring devices (such as wideband AC measurement standards and sources) operating in voltage range 1 mV to 3,5 V at frequencies up to 50 MHz. Moreover, the demands for the calibration of other laboratory equipment operating in voltage range 1 mV up to 50 V at frequencies up to 100 MHz, such as secondary RF-DC standards, function generators, insertion units (and potentially high-power sensors and attenuators and detecting elements) are continuously increasing and need to be covered.

Currently, there are only three European NMIs with published CMCs in the category "RF-DC transfer" based on RF-DC standards fully covering the bandwidth from 1 MHz up to 100 MHz and three others with published

CMCs in this category with reduced bandwidth. Uncertainties provided by already published CMCs are insufficient and cannot fulfil the requirements for AC voltage measurements in the frequency range from 1 MHz up to 100 MHz. A few European NMIs also published CMCs for the “RF voltage” category from 1 MHz up to 100 MHz based on microwave power measurements. However, none of these CMCs have sufficient accuracy to cover the needs of AC voltage measurements in this frequency range. A new realisation of AC voltage up to 30 MHz based on RF-DC standard has recently been developed at a university in Europe. The results of this realisation can be used to improve the traceable RF-DC measurement methods and thus the traceability for calibration of wideband instrumentation.

Developing a working setup for wideband AC voltage measurement requires expertise in electromagnetic metrology, particularly in low-frequency (LF) and radio frequency (RF) fields. Above 1 MHz, transmission line effects such as reflections and standing waves, as well as setup factors like grounding, guarding, and connector quality, become critical. Proper understanding of these issues is essential to bridge impedance-mismatched RF-DC measurements with impedance-matched wideband instrumentation and ensure traceability with sufficiently low uncertainty for calibration laboratories and industry. Further research needs to be undertaken to improve the knowledge of RF-DC measurement to further decrease the total measurement uncertainties. Those few European NMIs with published CMCs for RF-DC and RF voltage in the frequency range 1 MHz up to 100 MHz employ uncertainty evaluations that are specific to their particular measurement setups and are not directly applicable to others. A suitable theory of transmission line effects in an unmatched RF-DC based measurement setup has not yet been properly elaborated. To quantify the mismatch influence, coordinated parameter studies over a wide area of hardware properties need to be carried out.

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 proposal shall focus on the development of traceable regional/ national metrology capability in wideband AC voltage up to 100 MHz.

The specific objectives are

1. To develop novel RF-DC standards based on principle of thermal voltage converters at input voltages from 1 V up to 5 V and frequencies up to 100 MHz with target uncertainty better than 10 $\mu\text{V/V}$ at 1 MHz and 500 $\mu\text{V/V}$ at 100 MHz.
2. To investigate and extend the step-up and step-down measurement methods based on thermal transfer techniques for frequencies up to 100 MHz scaling from the basic voltage level of primary RF-DC standards (1 V up to 5 V) down to 1 mV and up to 50 V.
3. To develop traceable methods for providing conversion between impedance mismatched RF-DC standards and impedance matched (50 Ohm) wideband measuring instruments at frequencies up to 100 MHz based on investigations of the connections, connectors, cables, transmission line effects, hardware performance, grounding conditions including analysis of uncertainty contributions.
4. To develop, validate and provide at least two new working setups based on the novel RF-DC standards, extended step-up and step-down measurement methods, and traceable method for providing conversion between impedance mismatched and matched measurement. The targeted voltage range will be 1 mV up to 50 V at frequencies up to 100 MHz with the uncertainties 200 $\mu\text{V/V}$ (1 MHz) to 5 mV/V (100 MHz) at 1 mV, and of 100 $\mu\text{V/V}$ (1 MHz) to 2.5 mV/V (100 MHz) at 50 V. To operate the setup, an open software tool will be developed to control the hardware and evaluate the results.
5. To facilitate the take up and long-term operation of the capabilities, technology and measurement infrastructure for AC voltage measurements developed in the project, by the measurement supply chain (NMIs/DIs, calibration and testing laboratories), and end users (e.g. industry, instrument manufacturers, regulators). The approach should be discussed within the consortium and with other EURAMET NMIs/DIs, e.g. via EURAMET TC-EM and EMN for Smart Electricity Grids (SEG), to ensure that a coordinated and optimised approach to the development of traceability in this field is developed for Europe as a whole.

Joint Research Proposals submitted against this SRT should identify

- the particular metrology needs of stakeholders in the region,
- the research capabilities that should be developed (as clear technical objectives),
- the area for which the capabilities will be built (Green Deal, Digital Transformation, Health, Integrated European Metrology, Industry, Normative or Fundamental Metrology) and in which future main call the developed research capabilities are planned to be employed,
- the impact the developed research capabilities will have on the industrial competitiveness and societal needs of the region,
- how the research capability will be sustained and further developed after the project ends.

Where relevant, proposals are encouraged to build on, or seek collaboration with, existing projects and develop synergies with other relevant European, national or regional initiatives and funding programmes. In particular, links are encouraged with (i) the projects funded under earlier relevant topics of the Horizon Europe programme; or (ii) other relevant European Partnerships.

Proposers should establish the current state of the art and explain how their proposed research goes beyond this. In particular, proposers should outline the achievements of the EMPIR projects 15RPT04 TracePQM and 20FUN07 SuperQuant and how their proposal will build on those.

The development of the research potential should be to a level that would enable participation in other TPs.

Proposers should note that the programme funds the activity of researchers to develop the capability, not the required infrastructure and capital equipment, which must be provided from other sources.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 0.7 M€ and has defined an upper limit of 0.9 M€ for this proposal.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 20 % of the total EU Contribution across all selected projects in this TP.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated 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 proposal's results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Provide a lasting improvement in the European metrological capability and infrastructure beyond the lifetime of the project,
- Facilitate improved industrial capability or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- Transfer knowledge to the accredited laboratory sector, the instrument manufacturers and the metrology community.

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 the Metrology Partnership 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.

Timescale

The project should be of up to 3 years duration.