EMPIR Call 2015 – Health, SI, Normative and Research Potential

Selected Research Topic number: **SRT- s06**
Version: 1.0

Title: Metrology for terahertz technologies

Abstract

Over the last few years, the number and diversity of instruments operating at sub-THz and THz frequencies has grown rapidly. However, at frequencies above 110 GHz there are only limited measurement standards or procedures. Components for the next generation of communications and computing will be operating in excess of 110 GHz and new technologies such as graphene will require robust high-frequency measurements in order to move from laboratory to commercialisation. Therefore, the need exists to work on the development of measurement procedures and standards at sub-THz and THz frequencies and ensure that Europe maintains the leading position in this area.

Keywords

Microwave metrology, millimetre-wave, submillimetre-wave, time-domain spectrometers, vector network analysers, power sensors, THz metrology, GaAs, Graphene, radiometers, photo-mixers.

Background to the Metrological Challenges

High frequency (HF) instrumentation has progressed rapidly in the last few years and its applications have greatly expanded to spectroscopy, package inspection, ultra-fast wireless communications and sensing. In contrast, international metrology has not kept pace of high frequency instrumentation and now lags behind by an order of magnitude in frequency. A number of factors have contributed to the disparity between NMI capabilities and those of commercial systems, including instrumentation costs, fragmentation of technologies, niche applications and end user demand.

Existing continuous wave (CW) microwave calibration standards in Europe cover a broad range of frequencies, but none completely covers the 110 GHz to 5 THz region and only two European NMIs have a broadband terahertz system for 0.1 to 4 THz. For the 110 GHz to 1 THz region there are few high-accuracy power detectors and no calibration services available. Broadband terahertz time-domain spectrometers (TDS) pose particular challenges for power measurement in that they produce spectrally broad pulses from 100 GHz to 5 THz with a pulse length of ~1 ps and repetition rate of ~100 MHz, and with total average power of only 10 - 100 µW. Some types of highly sensitive thermal detectors can measure the total (spectrally integrated) average power, but their calibration and validation remains a major challenge. There are currently no calibration services or standards for TDS instruments anywhere in the world, and no agreed procedures for specifying instrument performance. Hence there is a strong requirement for the development of new THz detector and devices, and for the establishment of power standards.

In Europe, traceable measurement capabilities for HF power in coaxial lines are available in some European NMIs and in a few research labs for frequencies up to 50 GHz. Beyond that, only three NMIs offer calibration services for waveguide sensors up to 110 GHz. Maintenance of traceable calibrations beyond 50 GHz is endangered because the production of traceable millimetre-wave thermistor sensors has ceased in the 1990s, which explains the limited availability of remaining sensors for frequencies up to 110 GHz. Modern commercially available sensors are not usable as transfer standards, because their power detection principle (rectifying diode or direct heating of thermocouple) is incompatible with the existing calorimetric method. This requires the development of novel sensors that fulfil the traceability demands.

The calorimeter calibration of coaxial standards is established up to 40 GHz and results in significantly higher uncertainties compared with waveguide calorimeters. Beyond 110 GHz, traceable calorimeter calibration of waveguide power sensors as transfer standards cannot be performed in any European or international NMI.

Emerging technologies such as graphene promise the creation of very high frequency electronic circuits beyond 1 THz, whilst ongoing advances in semiconductor materials such as Si, GaAs, SiGe and InP are also being driven to create terahertz devices. Europe has been at the forefront of HF device technology, and with continuous metrology support in material measurement and device characterisation, the development and commercialisation of these products, will enable Europe to keep its position.

The possibility of measuring THz frequencies with high accuracy will enable the standardisation and certification of devices and systems that operate in the THz region as well as the expansion of THz applications with the subsequent benefits in various areas e.g. industry, defence, energy, health and medicine, information technology and communications.

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 measurement and characterisation of quantities at sub-THz and THz frequencies.

The specific objectives are

1. To extend traceable continuous wave power measurements in waveguide to 300 GHz and develop new thermoelectric sensors to be utilised as transfer standards to 300 GHz;
2. To develop new waveguide/coaxial/free-space power sensors for frequencies in the range 0.1 to 5 THz with a large spectral range and high sensitivity. This includes sensors for short-pulse (peak power) measurements, and sensors with optoelectronic mixers. The sensors with optoelectronic mixers shall work in the frequency range from 50 GHz to 2 THz and should have an estimated error of less than 1 % after calibration;
3. To develop and fabricate an optoelectronic mixer with a bandwidth better than 2 THz at both inputs (measurement and local Oscillator signals) and over 10 GHz at the output port (intermediate frequency). The target conversion efficiencies shall be in the range of 10^{-4};
4. To develop metrology and methodologies for measurements from 110 GHz to 5 THz for both waveguide-based and free-space systems. This shall include the establishment of calibration techniques and traceable frequency standards to serve both narrow-band high-resolution and broadband low-resolution systems, and traceable standards, verification techniques and uncertainty calculation methods for S-parameter measurements above 300 GHz;
5. To facilitate the take up of the technology and measurement infrastructure developed by the project by the standards developing organisations (e.g. IEC or CENELEC) and end users (e.g. accredited laboratories and industry).

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. A strong industry involvement is expected in order to align the project with their needs and guarantee an efficient knowledge transfer into industry.

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 HF Circuits project, SIB62, and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.8 M€, and has defined an upper limit of 2.1 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 21 % of the total EU Contribution to the project. Any deviation from this must be justified.

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 high-frequency instrumentation and communication sector.

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.