European Partnership on Metrology
Call 2025 – Health, Integrated European Metrology, Regulation and Research Potential

Selected Research Topic number: **SRT-s08**
Version: 1.0

Title: Advanced VNA-based microwave on-wafer measurements for electronics and 6G communications

Abstract

Semiconductor devices (planar integrated circuits) are critical to the European digital transformation and represent strategic assets in key high value industrial chains. Therefore, SI traceability needs to be established for a range of key microwave measurement quantities to support the development of advanced planar circuits, particularly semiconductor devices, operating at millimetre-wave and sub-terahertz frequencies. Traceability in this area is needed by emerging applications such as 6G communications. Proposals addressing this topic should focus on S-parameters (measuring the loss and phase change for transmitted and reflected electrical signals), electromagnetic fields, noise figures, and material characterisation (complex permittivity), all using on-wafer measurements. This will enable European NMIs and DIs to provide SI traceability for these vital measurement quantities, benefiting the communications, electronics, and semiconductor industries.

Keywords

SI traceability; On-wafer microwave metrology; S-parameters; Noise figure; Permittivity; Millimetre-waves; Communications; Electronics; Semiconductors, Vector Network Analyser

Background to the Metrological Challenges

Semiconductor devices' importance is evident in various applications, including future telecommunications, highly automated vehicles, and space technologies, especially highlighted by the recent global chip shortage. To address challenges in this area, significant global initiatives have emerged, such as the €43 billion "European Chips Act" in 2023 and the $52.7 billion U.S. "Chips and Science Act" in 2022. Furthermore, the millimetre-wave and sub-terahertz regions of the electromagnetic spectrum are becoming increasingly vital for these applications, offering benefits like ultra-wide bandwidth for backhaul and access technologies in 6G, high resolution for automotive radar sensors, and unique spectral fingerprints for identifying different chemicals or gases in satellite applications.

Despite the availability of measurement instruments, the development of circuits for these advanced applications is often hindered by the lack of traceability and therefore, there is an urgent need for new metrology at the NMI and DI level to establish this traceability, which is crucial for fully utilising the capabilities of existing measurement systems. The EU's efforts to create a resilient and secure internal supply chain for semiconductor chips by providing assured and traceable measurements will aid in the development of semiconductor standards.

Moreover, Vector Network Analyser (VNA) based on-wafer S-parameters measurement of multiport and differential circuits are widely utilised in advanced millimetre-wave systems for 6G and automotive radar sensing. European NMIs/DIs have made significant strides in establishing traceability for on-wafer S-parameter measurements up to terahertz frequencies. However, these initiatives have largely concentrated on two-port single-ended measurements as seen in previous Metrology Partnership, EMPIR and EMRP projects 23IND10 OnMicro, 14IND02 PlanarCal, 20IND03 FutureCom, 18SIB09 TEMMT and SIB62 HF-Circuits, and therefore indicating a gap that needs to be addressed to enhance the overall measurement framework for multiport and differential circuits.

Calibration and Measurement Capabilities (CMCs) listed in the BIPM databases or established calibration and traceability methods for differential measurements up to 40 GHz and beyond are currently not developed.

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Meanwhile, differential broadband measurement systems operating up to 220 GHz are commercially available now. Successfully addressing the proposed topic will enable European industry and academia to demonstrate traceability to the SI for on-wafer measurements of advanced planar circuits, significantly benefiting organisations involved in applications like 6G, connected autonomous vehicles (CAVs), and space technologies.

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.

Proposals should focus on the development of traceable on-wafer measurements of complex planar circuits, especially semiconductor devices, operating up to sub-terahertz frequencies.

The specific objectives are

1. To develop traceability and verification techniques for multiport and differential on-wafer S-parameters measurements at millimetre-wave frequencies up to 220 GHz. This includes selecting and investigating multiple possible calibration methods that correct for crosstalk between probe fingers and probes and producing a best practice guide, to ensure accurate calibration and measurement of planar on-wafer circuits with more than two ports.
2. To develop traceability and verification techniques for S-parameters and field mapping methods for connectorless 6G antennas (e.g. on-chip antennas) at millimetre-wave and sub-terahertz frequencies up to 330 GHz. This involves investigating the impact of on-wafer probes on the measurement of typical antenna characteristics. In addition, different field mapping techniques will be developed (with estimated uncertainties), compared and evaluated, including conventional methods (e.g. waveguide probes, electro-optic systems) and new methods (e.g. Rydberg atom-based systems).
3. To develop traceability and verification techniques for on-wafer noise figure measurements of planar circuits (e.g. transistors) up to frequencies of at least 110 GHz. In addition, to develop accurate and traceable dielectric characterisation methods for microwave substrates (including semiconductor wafers) at varying non-ambient temperatures up to 150 °C, and for defect inspection in semiconductor wafers, up to at least 220 GHz.
4. To demonstrate the establishment of an integrated European metrology infrastructure and to facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (e.g. EURAMET TC-EM, research institutes, calibration laboratories), standards developing organisations (e.g. IEEE P2822, ETSI mWT, ETSI THz), and end users (e.g. communications industry, electronics industry, semiconductor sector).

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 both within and outside Europe, plus engagement with existing European research infrastructures and European Partnerships 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 and end users. 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 project goes beyond this. In particular, proposers should outline the achievements of the EMRP or EMPIR or Metrology Partnership projects 23IND10 OnMicro, 14IND02 PlanarCal, 20IND03 FutureCom, 18SIB09 TEMMT and SIB62 HF-Circuits and how their proposal will build on those.

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 2.1 M€ and has defined an upper limit of 2.6 M€ for this proposal.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 25 % 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,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- 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 semiconductor 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 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.