Publishable Summary for 18SIB09 TEMMT
Traceability for electrical measurements at millimetre-wave and terahertz frequencies for communications and electronics technologies

Overview

This project aims to establish traceability to the SI for 3 electrical measurement quantities; (i) S-parameters, (ii) power and (iii) complex permittivity of dielectric materials, at millimetre-wave and terahertz (THz) frequencies. Such traceability is important for many emerging applications, exploiting communications and electronics technologies – e.g. 5th Generation mobile networks (5G), the Internet of Things (IoT), Connected and Autonomous Vehicles (CAVs), space-borne radiometers for Earth remote sensing, and security imaging, etc. The goal of this project is to support such emerging application and enable European NMIs to provide traceability to the SI for these 3 parameters in the millimetre-wave and THz part of the spectrum, which will be beneficial to end-users.

Need

The rollout of 5G networks and large-scale deployments of cellular IoT will lead to fundamental changes to our society, impacting not only consumer services but also industries embarking on digital transformations. CAVs are progressing rapidly and are expected to improve traffic flow, safety and convenience significantly. Space deployed radiometers are also used for passive remote sensing of atmospheric constituents which are related to climate change and play a critical role in environmental protection. All these applications require the use of the millimetre-wave and THz regions of the electromagnetic spectrum, and demand devices and integrated circuits operating at these high frequencies.

However, the development of devices and systems to underpin these applications is currently hampered by the lack of traceability for electrical measurements at millimetre-wave and THz frequencies. For example, although power meters working at frequencies up to at least 750 GHz are commercially available, there is no established calibration hierarchy, accessible to industrial and other end-users, to allow traceability to the SI for these measurements. In addition, current commercially available frequency extender heads and calibration kits for vector network analysers (VNAs) enable these systems to measure S-parameters at frequencies up to 1.5 THz. These VNA systems can also be adapted to measure materials properties (e.g. complex permittivity) using commercially available Material Characterisation Kits (MCK) at frequencies up to at least 750 GHz. However, again, there is no traceability to the SI to benchmark this measurement capability. NMI-level metrology research is therefore, urgently needed to address this lack of traceability so that the capabilities of these high frequency measurement systems can be fully exploited.

This is important to ensure product quality and end user confidence, and ultimately to improve the competitiveness of European Industry. The work in this project also aligns with broader European visions, as outlined in the Europe Commission Strategy i.e. “Digital Single Market”.

Objectives

The overall objective of this project is to achieve accurate and traceable electrical measurements for users of the millimetre-wave and THz regions of the electromagnetic spectrum, particularly for electronics applications impacting future communications technologies – so-called 5G communications and beyond.

The specific objectives of the project are:

1. To develop metrological traceability and verification techniques for S-parameters (that measure the loss and phase change for transmitted and reflected signals) in both coaxial line (using the 1.35 mm E-band connector to 90 GHz) and rectangular metallic waveguide (using waveguides covering frequencies from 330 GHz to 1.5 THz). Three waveguide bands within this frequency range will be covered and these are 330 GHz to 500 GHz, 500 GHz to 750 GHz, and 1.1 THz to 1.5 THz.

2. To develop metrological traceability and verification techniques for S-parameter measurements on planar substrates from 110 GHz to 1.1 THz. Three waveguide bands within this frequency range will be covered and these are 110 GHz to 170 GHz, 500 GHz to 750 GHz, and 750 GHz to 1.1 THz.
3. To develop metrological traceability for power measurements in waveguide to 750 GHz. Two waveguide bands within this frequency range will be covered and these are 110 GHz to 170 GHz, and 500 GHz to 750 GHz.
4. To develop metrological traceability for complex permittivity of dielectric materials to 750 GHz. Two waveguide bands will be covered and these are 140 GHz to 220 GHz, and 500 GHz to 750 GHz.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by other NMIs with the view of forming a coordinated network of NMIs that provide a comprehensive measurement capability as well as by the measurement supply chain (research institutes, calibration laboratories), standards developing organisations (e.g. IEEE P287 and IEEE P1785) and end users (i.e. manufacturers of telecom equipment, measuring instruments, absorber materials, etc).

Progress beyond the state of the art and results

Currently, metrological traceability for electrical measurements in the frequency range from 50 GHz to 1.5 THz is poorly served by the global NMI community. This global lack of traceability at these frequencies is demonstrated by the fact that there are no Calibration and Measurement Capability (CMC) entries in the BIPM key comparison database at any frequency above 200 GHz. Given the current rapid increase in use of this part of the electromagnetic spectrum (particularly for communications and electronics applications), this situation represents a serious gap in the services provided by the NMI community to stakeholders i.e. end-users in industry and academia.

Traceable S-parameter measurements in waveguides to 1.5 THz and in E-band coaxial lines to 90 GHz

The current state of the art for metrological traceability for measurements in coaxial lines is up to 116.5 GHz within Europe. The NMI of Japan is capable of providing traceability in waveguide up to 170 GHz, representing the highest frequency in the BIPM database. This project will extend the state of the art by putting in place traceability in waveguides up to 1.5 THz. This will complement the work carried out in the previous EMRP project SIB62 HFCircuits that included a preliminary study on the steps needed to establish traceability for waveguides up to 1.1 THz.

The E-band 1.35 mm coaxial connector has been recently introduced to support applications like 5G and 77 GHz automotive radar sensors. However, there is currently no traceability established for E-band connector measurements. This project will go beyond the state of the art by establishing both dimensional traceability and electrical traceability for E-band connector measurements, allowing industry to perform traceable measurements with known uncertainty.

Traceable planar S-parameter measurements to 1.1 THz

Currently there is no traceability established for on-wafer S-parameter measurements above 110 GHz. Another EMPIR project 14IND02 PlanarCal established traceability up to 110 GHz. This project will continue the work of 14IND02 and develop traceability and verification techniques for S-parameters to 1.1 THz. This will enable industry to characterise integrated circuits with confidence at these very high frequencies.

Traceable power measurements to 750 GHz

The current state of the art for power measurement is up to 110 GHz in waveguides. This project will put in place traceability for power measurement up to 750 GHz. Micro-calorimeter and transfer standards will be developed for the 110 GHz to 170 GHz band and novel approaches using a combination of quasi-optical (pyroelectric detection) and guided wave power measurement will also be explored. In addition, evaluation of the traceability of a commercial power meter will be carried out up to 750 GHz.

Traceable material measurements to 750 GHz

For materials measurement (i.e. complex permittivity) existing traceability services extend only to 110 GHz and currently this is only available at a few NMIs. This project will put in place traceability mechanisms to establish the quality of material measurements to 750 GHz and will expand the number of NMIs offering such services to those participating in this project. This will unlock the potential for using dielectric materials in applications demanding accurate knowledge of material properties, e.g. for space applications.

Impact

Impact on industrial and other user communities

This project will enable accurate and traceable measurements of three key electrical quantities at millimetre-wave and THz frequencies. This will have a direct impact on communications and electronics industries exploiting this part of spectrum. Notable examples include point-to-point backhaul for 5G communications, the IoT, radar sensors for CAVs, space-borne radiometers for Earth monitoring, and security imaging.

Improvement of measurement accuracy and establishment of measurement traceability will enable manufacturers to provide confidence in their measurements and specifications. This plays a key role in the customer/supplier relationships, for which products need to be demonstrated as fit-for-purpose (i.e. meeting specification), regardless of who is carrying out the test or when/where the test is being performed. Additionally, the outcomes of this project will allow manufacturers to specify products more precisely, leading to systems with better performance (e.g. lower energy consumption), which will in turn boost the product yields for the manufacturers and potentially reduce prices for customers.

This project will also significantly extend the measurement capabilities of the participating NMIs, to over 1 THz for S-parameter measurement and to 750 GHz for power and material measurement. This will lead to greatly improved access to, and dissemination of, measurement traceability for European accredited testing and calibration laboratories and manufacturers of test instrumentation. This will be beneficial for all end-users, including customers and suppliers of millimetre-wave and THz devices and systems.

The project's outcomes will be disseminated to stakeholders and industrial end users through (i) a Technical Advisory Group (TAG), formed of members from end-user industry and metrology communities. Such direct interaction with industry will ensure the project aligns with industrial needs and foster knowledge transfer; (ii) public training courses and workshops focusing on measurement and traceability issues at millimetre-wave and THz frequencies; and (iii) publications at scientific conferences, in scientific journals and trade journals.

Impact on the metrology and scientific communities

This project will involve eight of Europe's NMIs and hence will synergise their national metrology research programmes. It is fully recognised that no single NMI has, or will have, the capability to deliver all the work in this project. Therefore, this project brings together each NMI's capability in order to build a complete picture of capability that fully aligns with stakeholder needs. During the project, preparatory tasks will be undertaken to subsequently establish a coordinated network of NMIs, including the NMI of Argentina (INTI), that will provide a comprehensive measurement capability based on the outcomes of this project, and the previous EMRP project SIB62.

This project will also foster collaborations between five European experienced NMIs (i.e. METAS, LNE, NPL, PTB and VSL) and three relatively small NMIs (CMI, GUM and TUBITAK) whose metrology programmes are at an early stage of development in the field of electrical measurements.

Impact on relevant standards

This project will make substantial contributions to the following international standards and related documents, via representatives in the project consortium who are involved in these standards bodies:

- International standards developed by IEEE: P287, P1785, IEEE On-wafer Special Interest Group
- International standards developed by International Electrotechnical Commission: IEC TC46/SC 46F
- International metrology activities underpinning the SI: BIPM Key Comparison Database, BIPM database of CMC
- EURAMET guidance documents: Power calibrations and measurements, Materials properties measurements, in the range from 110 GHz to 750 GHz

Longer-term economic, social and environmental impacts

Economic impacts: The measurement science generated by this project will pave the way for development of emerging applications including future telecommunications, autonomous vehicles, the IoT, and security imaging. This will enable European businesses to move into these areas with confidence and will ensure a strong competitive advantage over organisations outside the European region. For established applications, e.g. measurement instruments and space radiometers, state of the art performance for them will ensure a commercial edge and allow European industry in these sectors to continue progress with key technologies and to attract business from global markets.

Social impacts: The social benefits of this project will be to retain a competitive advantage in Europe over worldwide competition on technology and thereby keep and grow expertise and much needed highly skilled electronic engineering and support staff jobs. This project also has wider social impact on quality of life enabled by greater data transport in mobile networks, medical diagnostics using THz imaging, easier and safer mobility using CAV and security scanning in public places such as airports.

Environmental impacts: Space radiometers play a key role in Earth monitoring, which provides information about global climate change and weather forecasting. This project will facilitate more accurate and traceable measurements at millimetre-wave and THz frequencies, yielding radiometers with better performance. Improved energy efficiency of components and systems will also be supported as a result of more accurate measurements, which will in turn support a reduction in energy consumption and should lead to a more sustainable environment.

List of publications

None

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<tr><td colspan="2">Project start date and duration:</td><td>01 May 2019, for 3 years</td></tr>
<tr><td colspan="3">Coordinator: Xiaobang Shang, NPL Tel: 020 8943 6643 E-mail: xiaobang.shang@npl.co.uk
Project website address: -</td></tr>
<tr><td>Internal Funded Partners:
1. NPL, United Kingdom
2. CMI, Czech Republic
3. GUM, Poland
4. LNE, France
5. METAS, Switzerland
6. PTB, Germany
7. TUBITAK, Turkey
8. VSL, Netherlands</td><td>External Funded Partners:
9. BHAM, United Kingdom
10. Chalmers, Sweden
11. FVB, Germany
12. ULILLE, France
13. WAT, Poland</td><td>Unfunded Partners:
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