Publishable Summary for 22RPT04 RFMicrowave2
Development of RF and microwave metrology capability II

Overview

In recent years, the requirements from industrial and other sectors for the reliable measurement of radio frequency (RF) and microwave (MW) parameters have increased as technology has developed and become more innovative. However, the capability to address the requirements of these stakeholders only exists in a limited form in some national metrology institutes (NMIs) and designated institutes (DIs) with emerging capabilities. This project will develop a robust and sound approach for the measurement of RF & MW quantities and the evaluation of the associated measurement uncertainties, that goes beyond the achievements in the EMPIR project 15RPT01 RFMicrowave.

Need

Currently, new technologies in the fields of health care, security, traffic management, environmental monitoring, advanced industrial production, quality testing and communications require novel measurement methods and devices, including those involving RF&MW technologies. The frequencies, complexity of systems and data rates are continuing to increase which brings new challenges to the underpinning metrology. The necessary progress in RF to THz metrology on the European level is only achievable through effective cooperation between European NMIs, DIs and their stakeholders. There are several crucial fields, such as measurement of RF power and related quantities e.g., attenuation, electromagnetic field intensity and antenna parameters measurements which influence the measurement capability and traceability in many other areas. With the emergence of 5G, frequencies above 18 GHz are being used more widely, and electromagnetic compatibility (EMC) testing will be needed at these frequencies, requiring improvements in the calibration of antennas and electromagnetic field probes. A unified approach to measurement uncertainty evaluation is needed to compare the results of interlaboratory comparisons and to claim uncertainties for commercial calibration services.

The range of complex measurements required in both the time and frequency domains will continue to grow to meet the needs of the fast technological progress in many areas. In addition to establishing traceability and reducing the uncertainty of existing quantities, there are measurement and metrology challenges that are currently not supported by leading and experienced NMIs. In some cases, CMCs do not yet exist in the BIPM's KCDB for particular quantities because their traceability to basic SI units is very complex. Such challenges identified by the EURAMET TC-EM SC RF&MW, CCEM, CEN/CENELEC and others and include new nano-devices, on-wafer measurements, nonlinear VNA measurements, performance evaluation of alternative EMC test methods, efficient antenna calibration algorithms, high-speed differential measurements and signal integrity, over-the-air measurements in wireless communications and many others. Effective cooperation of European NMIs/DIs on these big challenges and the development of new and improved measurement techniques, procedures and standards require the capability gap among NMIs/DIs to be reduced, which would also improve the ability to fulfil the needs of fast-growing local industries in some countries.

Objectives

The overall objective of the project is to improve the European measurement and research capability for RF&MW metrology and to strengthen the potential for future cooperation among European NMIs, DIs and their stakeholders.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EURAMET. Neither the European Union nor the granting authority can be held responsible for them.

European Partnership Co-funded by the European Union

The project has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

The specific objectives of the project are:

1. To develop traceable targeted RF and MW metrology capability for RF/MW power, attenuation (transmission coefficient) and return loss (reflection coefficient) (S-parameters) in the frequency range up to at least 18 GHz in institutes with less experience. The development will be tailored to the defined industrial and economic needs of participating institutes.
2. To develop measurement and calibration capabilities for antenna parameter measurements, in particular the antenna factor, in the fields covering communications and electromagnetic compatibility (EMC) in the frequency range up to at least 18 GHz in institutes with less experience.
3. To develop measurement and calibration capabilities for electromagnetic field intensity measurement in the frequency range up to at least 30 MHz in institutes with less experience.
4. To develop a unified approach to measurement uncertainty evaluation that will reflect the state-of-the-art methods currently being developed in the framework of other European research projects. The approach will cover full uncertainty evaluation for all metrology capabilities developed from the first three objectives.
5. To facilitate the take-up and long-term operation of the capabilities, technology and measurement infrastructure for RF, MW and EMC 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 will be discussed within the consortium and with other EURAMET NMIs/DIs, e.g., via EURAMET TC-EM and EMN MATHMET, to ensure that a coordinated and optimised approach to the development of traceability in this field is developed for Europe as a whole.

Progress beyond the state of the art and results

Metrology for state-of-the-art technologies in RF and microwave field presently exists in relatively few European countries, and the capability level of NMIs/DIs in particular areas differ across countries for both historical and economic reasons. This project follows up on the EMPIR project 15RPT01 RFMicrowave which ran from 2016 to 2019. In that project less experienced NMIs/DIs gained expertise in three areas: (i) S-parameters, (ii) RF power measurements, (iii) calibration and testing procedures for EMC using RF&MW metrology. This project will focus on topics and aspects that were not addressed in the 15RPT01 and will go beyond the state-of-the-art in several areas:

Advanced RF power measurement techniques

RF power traceability at the primary level is provided using a calorimeter, which is only available in several developed NMIs. Moreover, calorimeter measurements become very cumbersome and expensive as the frequency increases above 50 GHz, and the technique is only available for power sensors based on a thermal conversion principle. In other cases, secondary-level techniques for the calibration of power sensors are used. Another commonly measured quantity is RF attenuation, however primary level attenuation measurements require traceable standards, which are limited to MHz frequencies. Measurement of attenuation at GHz frequencies and reliable measurement of high attenuations (>100 dB) is therefore problematic, particularly in less experienced NMIs. More affordable and practical techniques are therefore required. This project will establish capabilities for (i) the automatic measurement of RF power and assessment of the Monte Carlo simulation methods for the calculation of uncertainties, which will be validated by a comparison of direct RF power measurement, (ii) RF power measurement and power sensor calibration (calibration factor) using a vector network analyser (VNA), and (iii) the measurement of S-parameters using VNAs and the measurement of attenuation using a spectrum analyser or another high-dynamic range device

Antenna measurements

Antenna measurements are very demanding due to the level of knowledge of the underlying principles of electromagnetic field theory, measurement equipment and laboratory facilities required. Although calibration of basic quantities such as antenna gain is well established in more experienced NMIs at frequencies up to tens of GHz using conducted tests (i.e., the antenna is generally connected to the analyser using a cable), currently there are significant challenges in the area of 5G communications for measurement of quantities over the air, i.e., without the use of cables. The project will (i) develop traceable methods for antenna calibrations in the frequency range 9 kHz – 40 GHz, (ii), investigate the advantages and disadvantages of different calibration techniques for antenna calibrations, (iii). validate the new capabilities for antenna calibration by intercomparisons, and (iv) produce a best practice guide on the calibration of antennas in different set ups.

Electromagnetic field measurements

Electromagnetic field measurements are also very demanding and require considerable experience. Low-frequency electric and magnetic field generation and measurements are available in some less experienced NMIs up to frequencies of tens of kHz, however, measurements at MHz or even GHz frequencies are currently offered only in more experienced European NMIs. The project will develop or improve capabilities for (i) electromagnetic field calibration in the frequency range from 10 Hz up to 40 GHz, including the generation of electromagnetic fields, and (ii) the measurement of electromagnetic field intensity, including reducing the causes of deviations between calibration results obtained from different realisations or different laboratories. The new capabilities for electromagnetic field generation and calibration will then be validated by intercomparisons. Finally, a best practice guide on how to build calibration capability for electric and magnetic fields over a full frequency range (i.e., 10 Hz – 40 GHz) will be produced. At the conclusion of the project, several less experienced NMIs will be able to build their own simple realisations of electromagnetic field intensity (parallel plate capacitor, Helmholtz coils, TEM cell) or utilise commercial solutions (fully anechoic chamber).

Outcomes and impact

At the end of this project, participating NMIs will have gained the necessary knowledge and skills to provide new or enhanced RF&MW services for their stakeholders. To ensure this, each participants' activities in the project have been designed according to their and their stakeholders' particular needs.

Outcomes for industrial and other user communities

The enhanced measurement capabilities in particular NMIs and DIs will help them to better engage with local industries and government bodies and address their needs. Accredited calibration laboratories that obtain traceability from NMIs and DIs as the ISO 17025 requirement will be able to send their measurement standards directly to a local NMI/DI rather than to NMIs/DIs abroad. EMC test laboratories across Europe will benefit from enhanced capabilities of NMIs and DIs in antenna measurements and electromagnetic field measurements. Best practice guides on antenna measurements and electromagnetic field measurements will be publicly available for stakeholders via the project website and open-access repositories. On-going interaction with stakeholders will be achieved through the project website, the LinkedIn discussion group and a Twitter group, and the project participants will also engage with target end-user communities via the project's workshops, meetings with technical working groups, as well as presenting the project's results at metrology conferences and in scientific publications.

Outcomes for the metrology and scientific communities

The project will establish new calibration services in particular NMIs and DIs (e.g., measurement of the calibration factor of power sensors using a VNA, measurement of high attenuation, calibration services for antennas, measurement of electromagnetic field intensity). Both small institutes that wish to develop new competences and also larger ones aiming to improve/broaden their capabilities will benefit from the project outputs. The project outputs including results of interlaboratory comparisons will be beneficial for extending accreditation scopes of NMIs in the future, and for supporting and establishing new CMC entries in the KCDB database. Gaining more experience with basic antenna measurements and calibration of antennas for EMC applications in this project will also allow participants to take part in more advanced research projects (e.g., in the European Partnership on Metrology). The individual strategies developed for each participant for the short and long-term developments of their research capability in microwave metrology will be discussed within the consortium and in the meetings with EURAMET TC-EM SC-RF&MW. These strategies will particularly focus on regulatory support, research collaborations with the members of the European research community, quality schemes and accreditation of the NMIs.

Outcomes for relevant standards

This project does not aim to directly influence existing international standards nor contribute to the development of new ones, although efforts will be made to contact standardisation bodies and share the results of the project with them. Project participants that are members of local standardisation working groups will inform those groups about the progress of the project regularly. The project will support active participation in committees such as the EURAMET TC-EM SC-RF&MW or EMN MATHMET. Stakeholders from outside the EURAMET community will be contacted (e.g. WELMEC) to learn about their own needs and how the project could support them, even indirectly.

Longer-term economic, social and environmental impacts

Mutual cooperation of project participants will create new personal connections and strengthen existing ones, so that the joint research efforts among European countries will be more efficient. The less experienced institutes will be better prepared for participation with leading European NMIs in challenging future project calls within the European Partnership on Metrology together, such as the 2025 Health and Integrated European metrology call and the 2026 Fundamental and Industry call.

Automated RF power measurement with measurement uncertainty calculation will significantly speed up the calibration process and thus save money for accredited calibration laboratories and their customers. Better RF&MW capability in NMIs and DIs may, in the long-term, help to harmonise RF&MW metrology and EMC tests, which will help European producers and manufacturers of automotive, consumer electronics, digital and communication equipment etc. to compete in the global market. The calibration methods for antennas and field probes will indirectly enable electronic device manufacturers to obtain conformity more readily with related standards; helping to reduce the costs associated with conformity assessment.

More reliable measurements of RF power, antenna parameters and electromagnetic field intensity will be beneficial for energy savings and the protection of citizens against non-ionising radiation from telecommunication base stations, which are very densely distributed in the forthcoming 5G networks, especially in city environments. The 5G base stations work with high power levels and use complicated multi-beam antenna systems to cover large areas with a quality signal. The ability to measure RF power and antenna parameters reliably may allow the communication systems to be designed with a smaller power margin and thus be more energy efficient. The 5G base stations' radiation became a source of public concern and have been identified as a potential health risk by the ICNIRP. Reliable measurement of electromagnetic field intensity in the vicinity of base stations (e.g., using the code-selective method) will allow potential violations of the recommended radiation levels to be identified.

The project's results will have an indirect social impact through the improved quality and safety of electronic devices. In addition, electromagnetic interference (EMI) radiated from incompatible devices can be considered as environmental pollution and can have environmental consequences that are comparable to vehicle exhaust emissions or wastewater discharge. The environmental consequences can also cause disturbance to machines and, exposure of the population to high electric and magnetic fields.

List of publications

-

This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

<table>
<tr><td colspan="2">Project start date and duration:</td><td>1 May 2023, 36 months</td></tr>
<tr><td colspan="3">Coordinator: Martin Hudlička, CMI Tel: +420 266 020 174 E-mail: mhudlicka@cmi.cz
Project website address: https://rfmwii.cmi.cz/</td></tr>
<tr><td>Internal Beneficiaries:
1. CMI, Czechia
2. GUM, Poland
3. IMBiH, Bosnia and Herzegovina
4. NSAI, Ireland
5. RISE, Sweden
6. SIQ, Slovenia
7. Trescal, Denmark
8. TUBITAK, Türkiye</td><td>External Beneficiaries:
9. KORAL, Italy
10. LeftRight, Slovenia
11. METU, Türkiye
12. SPARK, Türkiye</td><td>Unfunded Beneficiaries:
13. PTB, Germany</td></tr>
</table>