Publishable Summary for 15RPT01 RFMicrowave
Development of RF and microwave metrology capability

Overview

The radio frequency and microwave (RF&MW) field has undergone revolutionary changes in the last 40 years and today, RF&MW technology is more pervasive than ever. This is especially true for commercial markets, where modern applications include cellular and smart phones, wireless networking, direct broadcast satellite, television, global positioning systems, wideband radio and radar systems, and microwave remote sensing systems for environment, biomedical and healthcare applications (to name but a few). This project aims to develop research and measurement capacities as well as expertise for emerging EURAMET countries in RF&MW. It will do this by transferring theoretical and practical know-how between the project partners and by combining their skills to focus on microwave and electromagnetic compatibility (EMC) measurements. The outcomes of this project will be vital for reducing the gap between the European countries in terms of metrological capabilities in radio frequency (100 kHz – 300 MHz) and microwave frequency (300 MHz – 300 GHz).

Need

New technologies in the health, energy, security, environmental, industrial and communication sectors require novel RF&MW devices and measurement methods which currently are under research and development (R&D). However, this R&D brings new challenges to the underpinning metrology for RF&MW as it requires advanced technologies.

Scattering parameter (S-parameter) measurements, RF power measurements, EMC tests and calibrations are important areas in RF&MW metrology. These are used to ensure and increase product quality and end user confidence. For example, S-parameters are one of the essential parts of high frequency design which are used in the characterisation and modelling of linear RF&MW devices and systems. The reliability of S-parameter measurements depends on how well the characterisation and modelling of RF&MW components is performed, therefore, the devices used for this need to be calibrated accurately and their measurement uncertainty must be calculated precisely. However recent R&D has shown that the simplified characterisation and modelling approach that is currently used for RF&MW components is inadequate.

Most high frequency electronic devices include short distance communication units which generate low-power ($P \leq 0.01$ mW). In order to obtain traceable and accurate measurements at low-power in RF&MW metrology, power sensors which are used for low-power measurements must be characterised accurately. However, during the characterisation of the power sensors, the effect of each measurement parameter, especially the effects of harmonics at the output of signal generators, must be considered. Due to the difficulty of characterising harmonic effects, some less developed national metrology institutes (NMIs) ignore the effect of higher harmonics in low-power measurements and they are not able to characterise power sensors for low-power. There is also a problem with RF&MW high-power measurements ($P \geq 1$ W) used in long distance communication, broadcasting radar applications and other applications. Characterisation of high-power measurement equipment such as wattmeters is generally performed using an ‘attenuator and power sensor’ combination in which both are calibrated at mid-power level ($0.01\text{ mW} < P < 1\text{ W}$). The characterisation parameters of the attenuator and power sensor should be at the same power levels, however, this assumption does not describe the actual situation.

EMC is the interaction of electrical and electronic equipment with the electromagnetic environment, and other equipment. In order to avoid EMC related issues electronic goods manufacturers must test their products that are electromagnetically compatible with relevant regulations. However, new verification methods are needed to increase the quality of EMC test/calibration and measurements, in particular advanced verification methods using vector network analysers (VNAs). The development of new verification methods is also important for raising awareness of any problems before starting tests (i.e. just-before-test). Moreover, knowledge transfer

between EMC and RF&MW laboratories is very weak, which reduces awareness in measurements/calibrations and, therefore the overall quality of both EMC and RF&MW measurements.

The gap between developed and currently developing countries is growing constantly and this situation is even more pronounced for RF&MW metrology where not only knowledge and expertise are required, but also experience. In order to prevent further widening of this gap in RF&MW metrology, the knowledge and expertise of the more developed NMIs needs to be transferred to those NMIs with less experience.

Objectives

The overall objective of this project is to improve the European measurement and research capability for RF&MW metrology and to establish a basis for future cooperation between European NMIs. This will enable less developed European NMIs to build necessary research capacity, as well as improving their calibration and measurement capabilities (CMCs) and reducing the increasing technological gap between NMIs. The specific objectives of the project are to:

1. **Improve S-parameter measurements with lower uncertainty and to develop/enhance impedance and S-parameters traceability across Europe** by improving the measurement and research capacities of NMI partners and bringing them to level to be able to adequately support the needs of their stakeholders. The primary traceability and uncertainty budget for the S-parameter measurements will be established through calculable calibration standards with the use of specialised software tools.
2. **Improve the reliability and precision of RF power measurements under low and high-power conditions**, power sensor measurements for low-power as well as to investigate the effects of higher harmonics in the response of power sensors to cover the stakeholder needs. Also to provide the NMI partners the ability to measure and determine output reflection coefficients of signal generators via knowledge transfer.
3. **Investigate advanced calibration methods and established test procedures for EMC** with use of RF&MW metrology. EMC calibration methods will be improved for traceability of loop antennas and pulse generators and existing verification methods will also be improved for EMC immunity/emissions by using advanced RF&MW metrology methods and VNAs. Therefore, an efficient knowledge link will be established between EMC and RF&MW experts across Europe.
4. **Develop an individual strategy for each partner for long-term operation of capacity development**, including regulatory support, research collaborations, quality schemes and accreditation. Each partner will also develop a strategy to offer calibration services in their own country and in neighbouring countries. The individual strategies will be discussed within the consortium and with other EURAMET NMIs/DIs to ensure that a coordinated and optimised approach to the development of traceability in RF&MW metrology is developed for Europe as a whole.
5. **Identify key industrial and scientific needs for stakeholders in RF&MW metrology**. At the beginning of this project, a survey on stakeholders' needs will be conducted for these purposes. The results of this survey will be instrumental to maximise the impact of this project within the European community of NMIs and industrial end-users via knowledge transfer, training and dissemination for this purpose, meetings, hands-on training sessions, technical papers and best practice guides will be prepared.

Progress beyond the state of the art

This project will support modelling of calibration standards for S-parameters and rigorous uncertainty propagation through a measurement model that represents the entire measurement process from the calibration of the VNA to the result of the device under test (DUT). Advances in modelling and new software capabilities (VNA Tools II developed by METAS) have prepared the path to this more consistent approach that the project will use, and should provide better agreement with internationally accepted guidelines. METAS has transferred their knowledge and experience to the partners TUBITAK, CMI, SIQ, INTA, RISE, NIS and NQIS, as part of a training course on specialised software tools (VNA Tools II). These partners now have improved their S-parameter measurement ability and partners are currently in the process of characterising their measurement systems with the help of VNA Tools II.

The project also addresses the traceability with respect to the calibration of power sensors for low-power at partners GUM, SIQ, NQIS, NIS and INTA. The traceability approach is based on the experience of TUBITAK and CMI and will use characterised adapters and attenuators. So far, TUBITAK and CMI have established their own measurement setups and performed preliminary measurements regarding characterisation of diode sensors used for low power measurements. In addition to this, SIQ, INTA and CMI have produced and exchanged information about their proposed measurement setups and measurement techniques for the characterisation of 'attenuator and power sensor' combination in small- as well as under large-signal conditions. Moreover, SIQ, INTA and CMI produced and distributed information about harmonics effects on power measurements using low-power diode sensors and equivalent circuits. In addition, SIQ, INTA and CMI have established their own measurement setups for the measurement of the output VRC of a microwave generator. The strength of RF&MW and VNA metrology will be used by this project to increase the quality of EMC test/calibration and measurements, e.g., 'just-before-test' verification methods using VNAs. Such 'just-before-test' verification methods will be able to efficiently detect insidious issues just before conducting emission and immunity tests to increase significantly the quality of EMC measurements. To do this, SAE-ARP950 RE101 calibration methods were performed and compared to results of the three antenna method by TÜBİTAK. The project will also transfer knowledge and awareness from the EMC field to the RF&MW field and vice-versa. Consequently, this knowledge link between the two fields will support an increase in the quality of metrology and help to fill existing knowledge gaps with the joint research effort of TUBITAK, RISE, UPC and SIQ.

Results

Improve S-parameter measurements with lower uncertainty and to develop/enhance impedance and S-parameters traceability across Europe

In order to increase S parameter measurement accuracy among the project partners, primary traceability and uncertainty budget for the S-parameter measurements will be established through calculable calibration standards with use of specialised software tools. The project will also establish new measurement software for the project partners CMI, GUM, INTA, SIQ, RISE, NIS, NQIS and TUBITAK who regularly perform S-parameters measurements.

A training activity was held in November 2016, in which, the partners CMI, INTA, SIQ, RISE, NIS, NQIS and TUBITAK learned from METAS how to use specialised software tools (VNA Tools II) to evaluate reliable VNA measurement uncertainties. Partners have gained the ability for modelling of calibration standards for S-parameters and calculating rigorous uncertainty propagation through a measurement model and new software capabilities.

Improve the reliability and precision of RF power measurements under low and high-power conditions

To improve project partners' power measurement accuracy and capability on the characterisation of power sensors for low power measurement; this project will address the effects of higher harmonics on low power measurements; the measured VRC value of signal generators for power measurement; and the characterisation of high power attenuators for high power measurements, through training events, workshops and intercomparisons.

A workshop on the Monte Carlo (MC) method and training on characterising of diode-type power sensor have been organised. During the training partners INTA, NQIS, GUM and NIS gained from CMI and TUBITAK, experience in characterising of diode-type power sensor using direct comparison technique. Draft versions of protocols for two inter-laboratory comparisons have been prepared; (i) power sensor measurements for low-power and (ii) measurement of output voltage reflection coefficient of a microwave generator. A report about harmonics effects on power measurements using low-power diode sensors has also been produced and equivalent circuits for diode-type power sensors were identified based on the findings from this report.

Investigate advanced calibration methods and established test procedures for EMC

This project will attempt to integrate the strength of RF&MW metrology, specifically the use of VNAs, into EMC tests and calibrations. It will establish a link between the areas of RF&MW and EMC that does not only embrace the integration of RF&MW metrology into the EMC field but also promotes an efficient knowledge transfer/exchange between the two fields. Improved EMC test system verification using VNAs and just-before-tests, the effect of non-metallic objects on EMC test standards, and the traceable calibration of loop antenna using a VNA and pulse generator will also contribute to improving the EMC test and measurement capability

of project partners.

Common Mode (CM) loop impedance measurements of the test setups, by means of a VNA, were installed with different supports and with an actual EUT i.e. an electronic thermo-hygrometer which was intentionally made very susceptible to conducted immunity disturbance signals and then tested. Material properties of the samples which were used during test have been measured using WR430 waveguide.

Develop an individual strategy for each partner for long-term operation of capacity development

An individual strategy for each partner for long-term operation of capacity development, including regulatory support, research collaborations, quality schemes and accreditation will be produced.

Identify key industrial and scientific needs for stakeholders in RF&MW metrology

Stakeholders' needs will be identified by this project and so far a questionnaire to identify the RF&MW and EMC capabilities of emerging metrology institutes who are not part of this consortium was prepared and distributed. The collected questionnaires will be analysed and the needs of such NMIs will be determined.

Impact

At the end of this project, participating NMIs will gain the necessary knowledge and skills to provide 'new' or enhanced RF&MW measurements and services for their stakeholders. To ensure this, the participation of each partner in the project has been designed according to their and their stakeholders' particular needs. In addition, an individual strategy for each partner for long-term operation of capacity development, including regulatory support, research collaborations, quality schemes and accreditation will also be produced. To achieve the desired goal, two workshops and two training sessions have been completed on Monte Carlo methods, S-parameters traceability, advanced modelling and rigorous uncertainty calculation using specialised software and the calibration of diode type power sensors respectively. In addition, in order to identify the needs of emerging metrology institutes on RF&MW and EMC capabilities, a questionnaire has been completed and sent to emerging metrology institutes who are not part of this consortium. Further to these activities, there will be another 4 workshops and 3 training courses for project partners, collaborators and emerging NMIs (outside of the consortium) as the project progresses.

The knowledge gained from this project will also be disseminated to stakeholders and RF&MW communities through standardisation bodies, such as the Turkish Standards Institution - MTC 036 EMC national mirror group (Turkey), AEN/CTN 208 – Aenor Spanish Committee on Electromagnetic Compatibility (Spain) and SIST/TC EMC (Slovenia), as well as via international conferences and through peer-reviewed journal publications.

The project will also include 6 comparisons to disseminate knowledge and to establish and enhance the metrological performance of project partners. One such comparison will be organised among INTA, METAS, SIQ, NIS, NQIS, GUM and TUBITAK on output VRC of microwave signal generator and so far a draft technical protocol has been prepared and disseminated to the partners. Finally, the project will produce four best practice guides for stakeholders and end users, which will be available through project website. Three of the best practice guides will be related to power measurements on the calibration of power sensor for low-power measurements, high-power measurements and the harmonic effect on low-power measurements, and the fourth guide will be on the traceability of pulse measurement in EMC.

<table>
<tr><td colspan="2">Project start date and duration:</td><td>01 June 2016, 36 months</td></tr>
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<tr><td>Internal Funded Partners:
1 TUBITAK, Turkey
2 CMI, Czech Republic
3 GUM, Poland
4 INTA, Spain
5 RISE Sweden
6 SIQ, Slovenia</td><td>External Funded Partners:
7 NIS, Egypt
8 NQIS, Greece
9 UPC, Spain</td><td>Unfunded Partners:
10 METAS, Switzerland</td></tr>
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