Publishable Summary for 16NRM07 Vector SAR
SAR measurement using vector probes

Overview

Specific absorption rate (SAR) is a measure of the rate at which energy is absorbed by the human body when exposed to a radio frequency electromagnetic field (EMF) and must be evaluated during the production of smartphones. This project will provide the methods, software tools and datasets required for traceable calibration and uncertainty analysis of vector probe array systems (array of vector probes that automatically determines the 3D electromagnetic field mapping using amplitude and phase information through a 3D reconstruction algorithm), which are used to measure the SAR of emitting mobile telecommunication devices. This work will contribute to the international standard IEC 62209-3 and future standardisation of fifth generation (5G) devices within IEC Technical Committee TC 106. This project will enable the full-compliance of mobile telecommunication devices against IEC 62209-3 in terms of EMF exposure limits to be tested with better reliability, and will enable testing times to be reduced, which will benefit the telecommunications industry.

Need

The development of mobile phones is ever-increasing and approximately 1.3 billion smartphones were sold worldwide in 2014. In addition, the number of telecommunication protocols that need to be tested to assess SAR during the production of such smartphones has increased over the last decade. Therefore the methods included in the international standards IEEE 1528, IEC 62209-1 and IEC 62209-2 now require excessively long testing times to assess compliance with SAR restrictions. For example, a modern smartphone with more than 30 transmission technologies/bands embedded would require five weeks of continuous testing to demonstrate compliance with SAR limits using the diode probe and robot specified in IEEE 1528, IEC 62209-1 and IEC 62209-2. In addition, not all foreseeable usage configurations are tested, e.g. the display of the phone is not facing towards the user and separation distances are shorter than that specified in the user manual. Furthermore, upcoming and future communications standards, such as Long Term Evolution (LTE) Releases 10 to 12, will incorporate complex multiple-input multiple-output (MIMO) antennas that cannot be efficiently assessed using the systems specified in current published standards, as they do not measure phase. Multi frequency measurement is also a challenge for traditional SAR measurement technologies as none of them have the capability to distinguish between frequency contributions to SAR. To overcome these problems, new SAR measurement systems have been developed which use arrays of vector probes, also called time-domain sensors, i.e. sensors which measure phase and amplitude to “image” the fields in a sealed phantom, a shell representing the human body, filled with a tissue-simulating liquid. Using this approach, the time required to acquire data for the SAR measurement of a handset is reduced by a factor of at least 100 compared to that using a traditional single probe scanning system. However, methods for traceable calibration and well quantified uncertainty estimates for these new systems must be established before they can be adopted into documentary standards, and at present these methods cannot be used for full compliance testing against exposure limits for SAR.

Objectives

The overall objective of this project is to provide the essential methods, software, data and validation required for the successful completion of the international standard IEC 62209-3 related to the measurement of SAR from handheld wireless telecommunications devices using vector based systems.

The specific objectives are to:

1. Develop traceable methods for the calibration of time-domain probes i.e. single vector probes and vector probe arrays up to 6 GHz. In addition to verify the accuracy of such measurement systems after calibration and to determine the properties of associated sealed phantoms.
2. Establish methods for uncertainty propagation through multivariate models, using the principles given in the ‘Guide to the expression of uncertainty in measurement’ (GUM). This will include identifying the

sources of measurement uncertainties and their propagation through multivariate transformations for single vector probe systems and vector probe array systems.

3. Verify the reliability of measurement systems for a wide range of transmitter types and improve the measurement of telecommunication signals and SAR measurement for a wide range of device types. This will include the development of improved data processing used with time-domain probes.
4. Develop test protocols for MIMO devices using vector probe arrays in order to determine the maximum SAR value (worst case) by combining MIMO signal figures.
5. Facilitate the uptake of the developed measurement systems and contribute to the standards development work of the technical committee IEC - TC 106 on the successful adoption of IEC 62209-3 standard vector-based SAR measurement systems in Europe. In addition, to ensure that the outputs of the project are aligned with the needs of IEC - TC 106 and in a form that can be incorporated into the standards at the earliest opportunity.

Progress beyond the state of the art

Methods for the calibration of single vector probes and vector probe arrays
This project will go beyond the current state of the art by proposing a new calibration technique to address properly the regulatory issues encountered with probe array systems when measuring devices having a radiation field different from that used for the validation. A calibration method has been defined that allows the traceability of the electric field itself at the measurement points of the arrays rather than the 1 g SAR and 10 g SAR of a reference antenna. Traceability is established through a single vector probe that is calibrated in terms of amplitude using the traditional analytical field in a waveguide and in terms of phase using a calibrated vector network analyser. A monitoring method for dielectric properties of sealed phantom commonly used in probe array systems has also been defined and a paper is to be submitted to a peer-reviewed journal.

Methods for uncertainty propagation through multivariate models
This project will go beyond the state of the art by providing a method for the derivation of uncertainties using the new calibration method based on electric field magnitude and phase distributions from real-world devices in the head and body phantoms and stage by stage calibration of each single sensor sub-systems in the vector probe array. Software tools to model the propagation of errors through complex algorithms have been developed in order to relate the individual sensor uncertainties to the uncertainty in the 1 g or 10 g averaged SAR for a given field excitation. A paper is in preparation in view of a submission to a peer-reviewed journal.

Reliability of measurement systems and improvement of the measurement of telecommunication signals and SAR measurement
This project will go beyond the state of the art by investigating the reliability of vector probe array systems for measuring SAR from real-world devices i.e. source antennas of mobile phones. A set of measurands will be defined that will describe the complex field distributions on a 2D plane resulting from a given DUT, and its similarity to other distributions. The measurement of different signal protocols, taking the effect of signal modulation and separation distance into account will be analysed, and the results of the computed field distributions will be compared and validated. First measurements using an electro-optic probe have been carried out to characterize complex field distributions on a 2D plane. Consequently, the procedure for an interlaboratory comparison can now be defined based on these measurements.

Testing of MIMO devices using vector probe arrays
Work performed in this project will allow a clear evaluation of a method for determining accurately the spatial peak 1 g or 10 g SAR from MIMO devices using vector probe arrays, and will provide a metrological statement on the reliability of the measurement using vector probe arrays and post processing combination of the electric field. As a first step, a simplified demonstration model has been devised using two antennas and the method was published in the proceedings of an international conference. Further work is being done to increase the number of MIMO antenna elements, with simultaneous excitation schemes with arbitrary amplitude and phase weightings of the array,

Results

Methods for the calibration of single vector probes and vector probe arrays

This project is developing a method and uncertainty budget for the in-situ calibration of sensors in a vector probe array, which establishes the traceability of the amplitude and phase of the electric field itself at the measurement points of the array. A method has been devised for transferring the calibration from one antenna to another of the same type using an array system as the measurement device. A phantom prototype and a coaxial sensor have been designed, and monitoring the dielectric properties of the tissue-simulating liquid in sealed phantoms typically used with vector probe arrays has been demonstrated. The calibration process has been shown to enable the complex permittivity of the phantom to be measured to within approximately 5% (k=2). The calibration of an electro-optic probe manufactured by a project partner was carried out and validated using a classical waveguide calibration system for the E-field amplitude and a vector network analyser for the phase. Reference antennas have been selected and fabricated, and corresponding datasets in terms of the magnitude and phase of the field distributions have been evaluated by computer simulations. This will establish reference datasets from real-world devices in head and body phantoms, as currently available data is limited to 1 g and 10 g SAR values from validation sources (1 g and 10 g are averaging volumes of 1 cm^3 and 10 cm^3 of tissue, respectively, with a standardised head medium density of 1000 kg/m^3).

Methods for uncertainty propagation through multivariate models

This project has developed theory and software tools to model the propagation of errors through complex algorithms in order to relate the individual sensor uncertainties to the uncertainty in the 1 g or 10 g averaged SAR for a given field excitation. At present no such approach has been developed for these systems, and the approach of the GUM cannot be applied readily. A model that allows the peak SAR to be calculated for a generalised measurement system based on a probe array contained within a phantom has been produced. This model accounts for typical interactions between the probes of the array, where the aim is to insure traceability of uncertainty components to the already established relevant parameters such as the field magnitude calibration of an optical probe in a waveguide, the vector field calibration of a reference antenna through radiated field measured by the calibrated optical probe and the vector field array system calibration while measuring the field radiated field from the calibrated reference antenna.

Reliability of measurement systems and improvement of the measurement of telecommunication signals and SAR measurement

The validation antennas to be used for upcoming measurements have been defined and qualified. Regarding the vector optical probes, a set of measurements have been carried out on one type, and second set of measurements is scheduled in a few months on another type. This will help define the test protocol that will be implemented in order to describe the complex field distributions on a 2D plane resulting from a device under test (DUT), and verify the reliability of measurement systems. Whilst reference sources have been provided to emulate real devices under test, there are currently no metrics to compare the similarity of the field from a DUT with the reference sources.

Test protocols for MIMO devices using vector probe arrays

A new and efficient procedure for the evaluation of the true exposure level, quantified by the SAR level, has been developed for MIMO devices operating beamforming. This simplified procedure enables higher margin for minimizing the radiation and performance of such MIMO devices, compared to traditional conservative SAR evaluation that results from the unpractical testing of all antenna-array states of the device with systems that do not use the phase information and are less applicable to beam-forming systems such as MIMO antennas. Work on increasing the number of MIMO antenna elements, with simultaneous excitation schemes with arbitrary amplitude and phase weightings of the array is on progress.

Impact

A stakeholder committee of nine members has been set up which includes mobile phone and other communications technologies manufacturers, and research organisations. Most of these members participate in the standardisation process together with part of the consortium partners and therefore dissemination on the progress of the project is made easier. Five presentations have been given and one accepted for presentation in international conferences. One open access proceeding has been published and two papers are in preparation for submission to international peer-review journals.

Impact on industrial and other user communities

This project will enable manufacturers of vector-based SAR measurement equipment to have better quality control of their products and will provide greater confidence in their measurement accuracy. The consortium includes two of these manufacturers (ART-FI and KAPTEOS) and other manufacturers of these systems will be encouraged to join the stakeholder committee. The stakeholders are being updated on the progress and outputs of this project. A Skype training course dedicated to industrials has been given in conjunction with a standardisation TC meeting. Moreover, a secondment has been arranged between NPL and KAPTEOS where KAPTEOS personnel could use NPL facilities and gain expertise in E-field calibration, isotropy/directivity and linearity characterisation. The result was the validation of the KAPTEOS vector probes in terms of performances at NMI level. The wider impact to industry will be achieved by incorporation of the vector array systems into IEC standards, which will enable the use of these systems by test houses for testing full compliance of mobile telecoms devices against exposure limits. This will result in considerable cost savings for device manufacturers and will reduce the time to bring new products to market. This will also reduce the significant costs associated with the annual calibration of the validation antenna set by around 75% compared with existing methods in the standard, so offers significant advantage to the users of these systems. It will also increase public confidence on the safety of the devices.

Impact on the metrology and scientific communities

The outputs of the project will enhance the partners' knowledge of metrology for EMF safety and of the statistical analysis of vector-based SAR measurement systems, leading to further metrological advances in these areas. Results have been shared with the wider scientific community through presentations at international conferences, and an opportunity was taken at one of these conferences to hold a booth and present a poster in a dedicated session where several stakeholders from Europe and Internationally have been approached and informed on the status of the project in regard to the IEC 62209-3 standard. The project's results have also been presented to CCEM-GTRF and EURAMET TC-EM RF&MW. These two subcommittees report then to CIPM-CCEM and EURAMET-TC-EM committees. Full open access will be provided to datasets, software tools and documentary reports on the project website and through other databases e.g. the partners' websites, to facilitate new scientific studies in this and related areas.

Impact on relevant standards

This project will be crucial for the successful completion and adoption of the IEC 62209-3 standard by providing the required calibration and uncertainty analysis methods and text in view of future revisions of the standard. The partners have been liaising with IEC - TC 106, in particular with the IEC - TC 106/PT 62209-3. Several partners are part of this working group, which is developing the IEC 62209-3 standard to disseminate the outputs of this project and seek feedback, so that they can be incorporated into the written standard when this is published. Results have also been shared with IEC TC106 'Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure', in particular i) MT1 (responsible for the maintenance of IEC 62209-1), ii) MT3 (responsible for the maintenance of IEC 62232) and iii) PT 62704-4 'Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Body from Wireless Communications Devices, 30 MHz - 6 GHz - Part 1:General Requirements for using the Finite-Difference Time-Domain (FDTD) Method for SAR Calculations'. Additionally, the project has been presented to CENELEC TC 106X 'Electromagnetic fields in the human environment'. Final results will be provided to IEC TC106 as written reports and guides that are suitable for adoption into the standards. These reports will be disseminated to the wider IEC - TC 106 committee to facilitate the development of standards on EMF safety of other devices and the development of standards in support of 5G, which is a stated priority of the IEC - TC 106.

Longer-term economic, social and environmental impacts

This project will ensure that 5G device compliance with safety limits for EMF can be demonstrated, which is an essential step in the implementation of this new technology. This will help i) to move towards a harmonised set of standards for assessing SAR from wireless devices, ii) to allow a dramatic cost reduction of bringing new LTE smartphone models to market thanks to reduction in the measurement time from a few weeks with a single probe to a few hours with a vector probe array and iii) to allow reduction of global power consumption thanks to efficient strategies for assessing SAR from MIMO and beamforming technologies. This work will also facilitate the introduction of MIMO, LTE 4G, 5G and IoT devices by ensuring that their EMF safety can be assessed, in line with the increasing demands of users for network data capacity.

List of publications

D. Allal, “EMPIR European project for validation of vector array SAR measurement systems”, 19th International Congress of Metrology, Paris, 2019, https://doi.org/10.1051/metrology/201902003

L. Aberbour, “Efficient Experimental Assessment of the Specific Absorption Rate (SAR) induced by MIMO Wireless Communication Devices; Application of Vector Near-Field Measurement System”, 2018 IEEE Conference on Antenna Measurements & Applications (CAMA), https://hal.archives-ouvertes.fr/hal-02376333

Project start date and duration:	01 May 2017, 36 months	
Coordinator: Djamel Allal, LNE	Tel: +33 1 30 69 21 50	E-mail: djamel.allal@lne.fr
Project website address: http://empir.npl.co.uk/vectorsar/		
Chief Stakeholder: n/a	Tel: n/a	E-mail: n/a
Internal Funded Partners: 1. LNE, France 2. NPL, United Kingdom 3. TUBITAK, Turkey	External Funded Partners: 4. ART-FI, France 5. IMTelecom, France 6. KAPTEOS, France	Unfunded Partners:
RMG: -		