Publishable Summary for 16ENG06 ADVENT
Metrology for advanced energy-saving technology in next-generation electronics applications

Overview
The roll-out of 5th Generation (5G) telecommunications across Europe by the year 2020, and the emergence of the Internet of Things (IoT) with 50 billion connected devices, will strongly increase the demand for energy due to the continuous power consumption of the electronic devices needed to deliver these technologies, leading to an associated demand for more energy-efficient systems. This project establishes the metrology required for this transformational objective for Europe by providing traceable measurements of power, losses and emerging electronic materials properties. Thus this project will enable European industries to optimise device and systems design for 5G and IoT applications requiring ultra-low power and more energy efficient operation.

Need
The ongoing IoT and the future 5G radio access network will have a fundamental impact on the daily life of all European citizens. Sensors (the cornerstone of IoT) will be found everywhere (car, house, industrial health monitoring, etc.) and 5G communication systems will provide greater connectivity (Machine-to-Machine, high data rates with low latency). The high data-rate aspect of 5G at mmWave frequencies makes the power consumption and thermal issues very challenging in wireless devices. By 2020, the Information and Communications Technology (ICT) sector is expected to contribute about 2 % of global CO2 emissions instead of 1.3 % in 2007 (Ericsson report, 2010). Within this, 20 % of the footprint may be attributed to personal mobile networks and mobile devices. Phones and tablets will produce the strongest percentage increase in the ICT's footprint: recent estimations forecast 50 billion devices enhancing the footprint by a factor of 4.

Improvement of the energy efficiency of devices and processes is therefore a key component for sustainable development of European products. Due to restrictions in current scaling strategies and dramatic thermal issues (particularly in wireless systems), semiconductor and electronics manufacturing roadmaps are aimed at the introduction of novel materials, more complete component characterisation and more efficient power management at the system level that will lead to the development of novel ultra-low power devices. To support industry in facing these challenging issues, traceable measurement techniques are required that will establish a robust metrology framework for in-situ, in-operando and multiphysics characterisation of advanced materials and components, and for reliable and accurate data for an efficient power management system.

Objectives
The overall objective is to achieve traceable and accurate measurements of the power consumed by ultra-low power and high frequency energy efficient electronic materials, devices and systems in order to support their development in both industrial and research sectors.

The specific objectives of the project are:

1. To develop nanometrology adapted to the in-situ and in-operando characterisation of advanced new materials proposed for the next generation of ultra-low power energy-efficient devices. These measurements will include impedance measurements (capacitance, resistance and inductance), piezo-electric/piezoresistive stress (200 MPa) and strain (0.02 %) responses to the application of electric (up to 4 MV/cm) and magnetic (up to 2 T) fields, as well as temperature and pressure in the range encountered in electronic devices.

2. To develop frequency and time-domain techniques for the simultaneous measurement of dynamic thermal profiles, electro-magnetic field sensing, DC electrical power consumption and RF operating waveforms for a wide range of RF electronic components (operating in-situ, under realistic conditions). These techniques to be combined with a multi-physics approach, which will establish rigorous energy budgets, and diagnostic capabilities, for a wide range of electronic components (operating in-situ, under realistic conditions), required for next-generation communications. The uncertainty in the measurement of the power efficiency to be reduced to less than 1 %.
3. To develop embedded sensors and the associated calibration and measurement techniques to accurately measure power consumption of wireless systems (mobile phones, tablets and connected devices) and to improve the effectiveness of analogue and RF tests of components and systems. The power measurement techniques will be able to characterise and calibrate on-chip power sensors with an uncertainty of less than 10 µW.
4. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (accredited laboratories), standards developing organisations (ISO) and end users (the semiconductor industry, and the telecommunications sector).

Progress beyond the state of the art

This project will act at three different scales (materials, components and systems) to support European industries in the development of optimised energy devices and systems required for 5G and IoT applications.

Materials

The characterisation of novel materials, such as ferroelectric, multiferroic, and piezoelectric-resistive materials, requires a joint effort in improved impedance, material structure and compositional metrology. Currently, the impedance measurement and structural analysis at nanoscale of such materials suffers from a lack of traceability, insufficient resolution and reliability. This project will develop a broad platform of metrologies to extend the spatial resolution of material structure and compositional measurement down to the nanometre scale, to quantify impedance of novel materials with an uncertainty of 10%, and to extend measurement of stress and strain responses to electric field up to 4 MV/cm and magnetic fields up to 2 T.

RF components

RF electronic components are never single transistors and it is critical to understand design limitations by measuring the electromagnetic fields, temperatures and losses distribution as the device operates. In Europe, no metrology basis exists to measure simultaneously and in-operando the electromagnetic and thermal responses of RF and microwave components under realistic operating conditions and to measure switching losses accurately. This project will combine a range of contacting and non-contacting techniques to reduce the current uncertainty in evaluating the power efficiency of such electronic components from 2% to 1%.

Systems and devices

To optimise the power consumption and system performance of battery-supplied devices, it is necessary to monitor and adjust the transmitted RF power accurately and continuously. On-chip power levels measured in these devices can be as low as the micro watt level. Even if power and thermal measurements are becoming increasingly integrated by many semiconductor suppliers at chip level, the traceability of on-chip power measurements does not exist at NMI levels. This project will develop traceable high frequency power metrology for on-chip power measurements with an uncertainty of less than 10 µW.

Results

Nanometrology for characterisation of new materials

The 1st objective aims to develop the metrology required in Europe for the measurement of impedance at nanoscale and characterisation of advanced materials such as piezo and ferroelectric materials. To support end-users in electrical properties measurements at nanoscale (such as high permittivity and losses of nanomaterials) this project will develop new impedance standards and identify error sources involved in very small capacitance measurements (down to the attofarad range). The first experiment results prove the ability of the Scanning Microwave Microscope (SMM) to make measurements of very low capacitance values (down to the attofarad range) and preliminary designs of impedance standards (capacitance, resistance and inductance) have been established which constitutes the first step towards the traceability of SMM instruments. Regarding the characterisation of advanced materials a large variety of experiments has been carried out which establishes the first milestone for the development of a European nanometrology adapted to the in-situ and in-operando characterisation of these new materials. Mesoscale and Analytical in-situ x-ray characterisation studies (including preparation of suitable samples), and preliminary X-ray diffraction and EXAFS measurements have been performed to respectively study stress/ strain responses of a piezoelectric crystal and evaluate synchrotron capabilities for the future experimental campaign. A table of a large variety of samples (piezoelectric, piezoresistive samples) has been established on the basis of the input of partners. The samples will be distributed to all involved partners for the future measurement campaign.

Multiphysics characterisation of RF components

This 2nd objective aims to develop and combine time- and frequency-domain, electromagnetic field and thermal mapping measurement techniques to establish rigorous energy budgets, and diagnostic capabilities, for a wide range of electronic components (operating in-situ, under realistic conditions), required for next-generation communications. A variety of non-contacting and contacting methods have been put in place in order to achieve the target of simultaneous measurements (dynamic thermal profiles, electro-magnetic field sensing, DC electrical power consumption and RF operating waveforms) of RF and microwave devices used for 5G applications. Efforts have been made to set up the experimental benches required for electromagnetic and thermal device characterisation and to train users within the consortium. The measurement process of the time domain method has been established successfully and the programming code for measuring switching losses is progressing very well. The time-domain method, algorithms and tools are therefore in place for the loss measurements of high-speed switching devices such as GaN, MOSFET and IGBT transistors.

Power consumption measurement of wireless systems and devices

This 3rd objective aims to provide to industry low cost and traceable sensors and fast scanning measurement data to improve on-chip power traceability. The first aspect is to design an on-chip power sensor for measuring micropower levels and establish its traceability to the International System of Units (SI). During this period the design has been made: the sensor is based on a Schottky diode using the latest BICMOS 55 nm technology from ST Microelectronic which will make possible its exploitation by 5G mobile manufacturers. To ensure the best performance of the detector a complete modelling of the Schottky diodes has been established during this first period of the project. The modelling results demonstrate a very high sensitivity of the device at the 5G targeted frequencies and avoid a difficult matching process. The first steps towards the traceability of the sensor to SI are underway: the basis of the on-chip direct comparison system, main component of the calibration method, has been implemented. The second aspect of this objective is to perform a characterisation of Printed Circuits (PCs) to be able to predict locally unexpected power loss levels over the complete tested device area. To this aim a 2D current reconstruction method has been fully implemented and validated based on electromagnetic simulations (HFSS) data for multiple conductor structures. It constitutes the first step towards a 3D power mapping method operating at higher frequencies that will go beyond the state-of-the-art.

Impact

Three presentation proposals have already been accepted to Keysight workshops at different European locations, and one paper accepted at the European Microwave Week conference (EuMW 2018), the major Microwave conference in Europe. Efforts have also been undertaken to present activities though newsletters and flyers.

Impact on industrial and other user communities

Outputs from the project will directly improve material and component characterisation as well as accuracy of power sensors, which will be used by industry to improve their systems' performance at lower cost: improvements boosting performance and functionality at all levels (device, circuit, system), and, in particular, in relation to the few critical parameters such as: power consumption, operating frequency, switching time, throughput, and device or circuit complexity. This project will enable the increase in performance of power management systems - the cornerstone of wireless mobile devices. Outputs in x-ray spectrometry and related atomic fundamental data will be fed directly into a recent academic and industrial international roadmap at LNE-LNHB (www.nucleide.org/IIFP.htm). Impedance standards fabricated in the framework of the project will be available for end-users of scanning probe instruments.

At this early stage, all efforts have been focused on the constitution of a project advisory group (PAG); collection of feedback on the strategy and first preliminary results of the project by collaborators and PAG members.

The PAG comprises seven end-users from industry (semiconductor, electronic, instrumentation), research centres and university, covering all the required expertise to review results and guide their exploitation. Six collaborators also support the technical activities carried out in the project and have expressed their interest in the results by signing letters of agreement. A meeting dedicated to PAG members and collaborators was held on the 23rd April 2018 at PTB (Berlin, Germany).

A meeting was organised on 9th April 2018 at LNE Trappes (France) with two key representatives from Alliance Electronique. This organisation is the major French professional union for industry and manufacturers in the electronics sector. During this meeting a discussion was carried out to organise the dissemination of results to manufacturers and industrial members of Acsiel Alliance Electronique.

Impact on the metrological and scientific communities

Scientific communities will benefit from new extended measurement capabilities: (i) a high-level platform in nanometrology (nanoscale impedance, stress and strain, X-ray, LIMM), (ii) a unique test-bench assembling different measurement techniques (electromagnetic measurements in the time-and frequency-domain, thermal mapping); and, traceable on-chip low cost power sensors. Successful outcomes of the project will therefore be submitted for publication in high impact peer-reviewed journals and, as part of the knowledge transfer, two specific workshops (on materials, on characterisation of electronic components and power measurements) will be organised and held. Representatives of industry (both manufacturers and users), academics and NMIs will be invited to these workshops.

Impact on relevant standards

Project progress and engagement will be reported at IEC (TC 47, 49 and 113), ISO (TC46 and TC206), IEEE (P1859/D6), VAMAS (TWA24) and EURAMET TC-EM SC-RF&MW/EMC, SC-LF committees through dissemination of good practice guides and organisation of meetings dedicated to standardisation activities relating to semiconductor devices, piezoelectric and dielectric devices and characterisation of materials at the nanoscale.

ADVENT activities and research results have been presented to a meeting of the IEEE Ultrasonics, Ferroelectrics and Frequency Control Society (technical working group Std P1859). This organisation is involved in the Draft Standard for Relaxor-Based Single Crystals for Transducer and Actuator Applications which is directly related to the project outcomes.

List of publications

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Project start date and duration:	1 September 2017, 36 months	
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