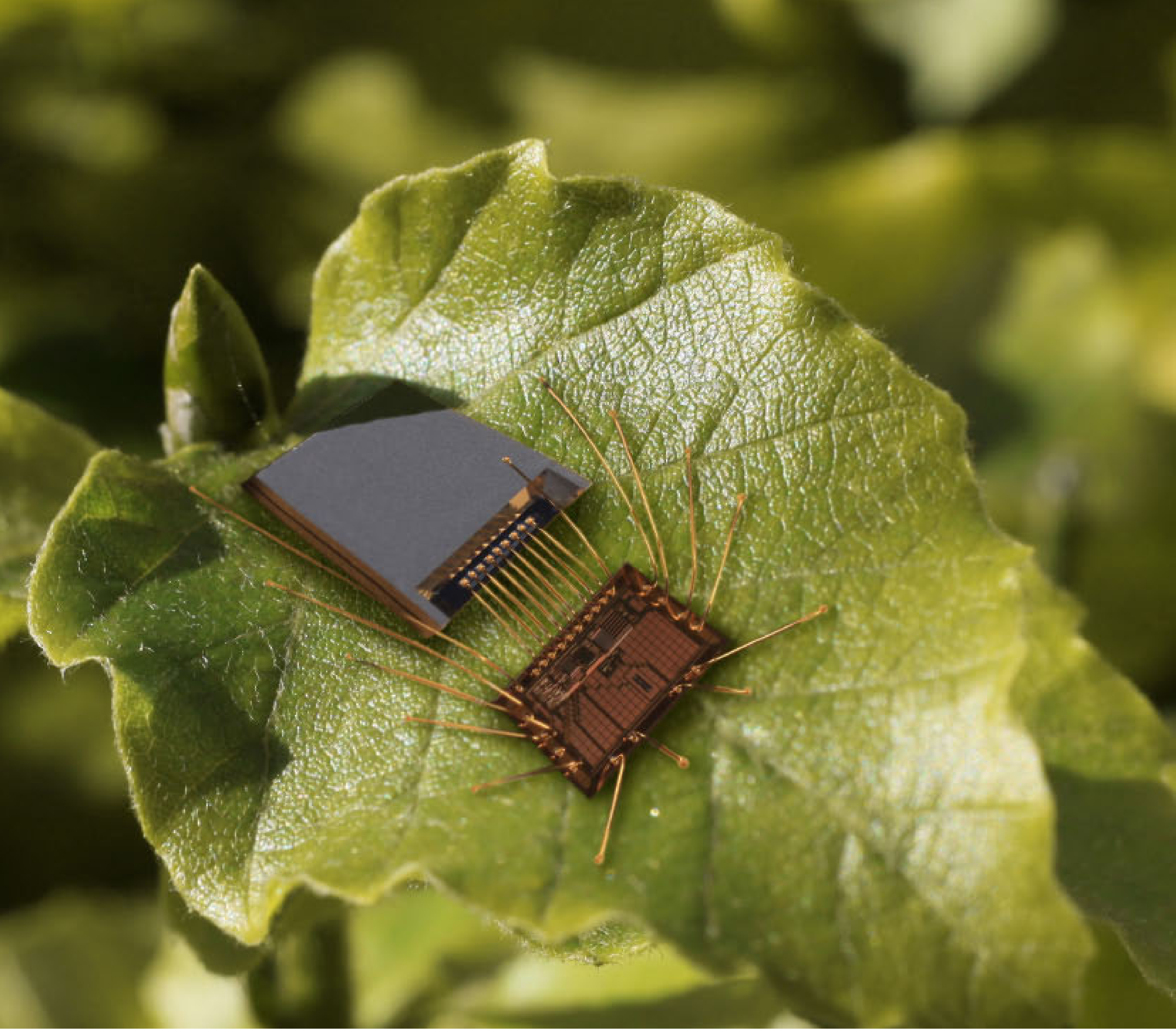

IMMS

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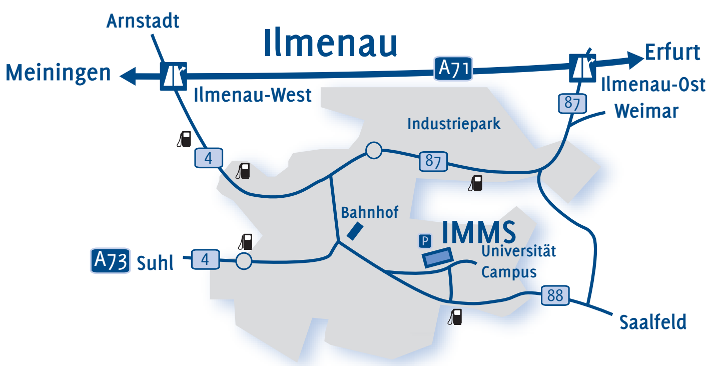

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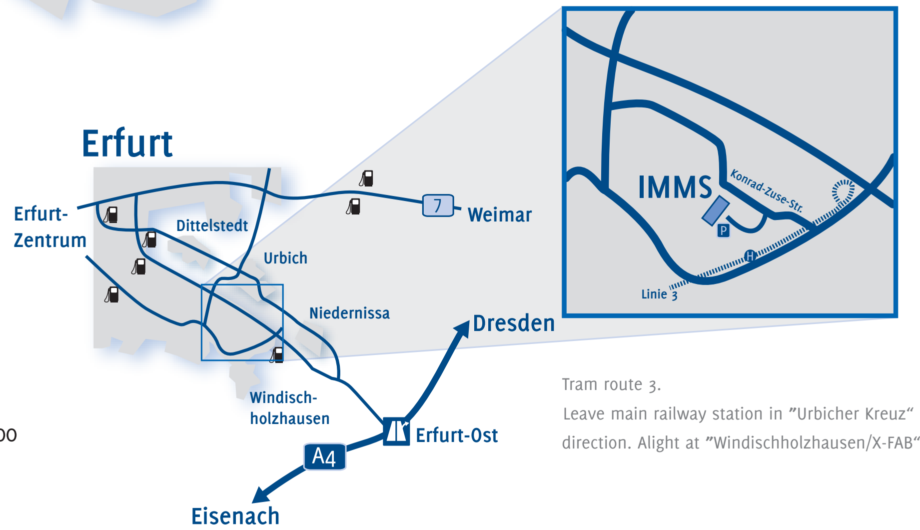

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IMMS

We connect IT to the real world.

Abbreviations

ASIC *Application-specific integrated circuit*
BAW *bulk acoustic wave*
BMBF *Bundesministerium für Bildung und Forschung (German Federal Ministry of Education and Research)*
BMWi *Bundesministerium für Wirtschaft und Energie (German Federal Ministry of Economic Affairs and Energy)*
CMOS *Complementary metal-oxide-semiconductor*
CPS *Cyber-physical system*
DAC *Digital-to-nalog converter*
DFG *Deutsche Forschungsgemeinschaft (German Research Council)*
DLR *Deutsches Zentrum für Luft- und Raumfahrt e.V. (National aeronautics and space research centre of the Federal Republic of Germany)*
EDA *Electronic Design Automation*
EFRE *Europäischer Fonds für regionale Entwicklung (European Regional Development Fund)*
FEM *Finite element method*
FPGA *Field Programmable Gate Array*
FTE *Full-time equivalent*
HTTPS *Hyper Text Transfer Protocol Secure*
IC *Integrated Circuit*
ICT *Information and communications technology*
IP *Intellectual Property*
LCR *test unit for the measurement of inductivity, capacity and resistance.*
LTE *Long Term Evolution, 4th generation mobile communication standard (3.9G)*
MEMS *Micro-electro-mechanical system*
OCIT-C *Open Communication Interface for Road Traffic Control Systems – Center to Center*
OLED *Organic light-emitting diode*
PWM *Pulse width modulation*
PXI *PCI eXtensions for Instrumentation*
RFID *Radio-frequency identification*
SiCer *silicon-and-ceramics substrate*
SoC *System-On-Chip*
SOI *Silicon on insulator*
TU *Technische Universität (University of Technology)*

Contents

Prof. Dr. Ralf Sommer (right) and Dipl.-Ing. Hans-Joachim Kelm (left). Photograph: IMMS.

Thank you for your interest in IMMS. Our Institute has been intensely active in 2015, helping our partners by bridging the gap between the first idea and a new application – both for them and with them. In our interdisciplinary projects, we have not only achieved the sort of pure research result that promises well for future technology but also produced ready-to-market solutions and devices. The future-oriented work has paved the way for the approach of Industry 4.0, Smart Mobility, the Digital Society, and Personalised Medicine as they come ever closer over the next few years. In pursuit of these visions, it is our intention to continue strengthening our bonds with joint networks, clusters and commissions, building up our research infrastructure, fostering the talents of young scientists and involving them early in well-chosen tasks.

We are pleased with our 2015 achievements. Our scientific work at two leading international conferences was awarded as best paper an best demo. In addition, our industrial partners are highly appreciative of the eminently usable results we together produce and the constructive and efficient way they are produced. What we have achieved so far spurs us on to stay the course as a competent, reliable research partner enabling new developments to cross the divide between science and industry.

The funding of our Institute by the German 'Land' of Thüringen has given us the means to support all this activity. We express sincere thanks on behalf of the team and the industrial partners who have gained competitive edge from the help. Local SMEs, above all, have in IMMS the only Thüringen research centre for microelectronics and mechatronics. IMMS serves them not only technologically at the regional level but also by linking them together in widely coordinated public schemes which promote industrial progress. In recognition of the responsibility entailed, we have guidance from our Scientific Advisory Board and our Board of Directors on how to realise the policies in which we are agents. We are very grateful to these two bodies for their commitment. Our thanks go, too, to the Ilmenau University of Technology for superb cooperation, which constantly enriches our work, and, more than that, brings such close research collaboration that synergy effects are felt in both establishments right across the boundaries between disciplines. Thank you all – sponsors, business partners, friends and every person bearing us up in our endeavours.

And, within IMMS, thanks go to staff and students for the constructive, reliable way they contribute their knowledge and their efforts to promote our shared future.

This foreword and this report bring you an invitation to join us in our forward thinking and accompany us along our way.

Prof. Dr.-Ing.
Ralf Sommer

Dipl.-Ing.
Hans-Joachim Kelm

Collaborating with Ilmenau University of Technology

Being an affiliated institute of Ilmenau University of Technology (TU), IMMS benefits from networking with the university while the TU benefits from the Institute's close relations with industry. The year 2015 saw IMMS working on shared research projects with 28 of the University's departments across the range – electrical engineering and computer science, mechanical engineering, information technology and automation, media and communications science. In parallel, the Institute has continued to operate in a compact industrial network, in the form both of industrial clusters and of regional and national innovatory networks. These fields include automotive engineering, microtechnology, microelectronics and optics. Valuable impetus is given by the groupings. They are the chance to pool skills, make shared use of partners' technology and develop joint marketing strategies.

Joint research projects

The MUSIK research cluster entered its Phase Two in 2015. Here, IMMS and Ilmenau University of Technology are working together on universal design methodology for the complex high-frequency circuits associated with MEMS. Some of IMMS' initial results are presented elsewhere in this annual report.

In the fast-wireless project, IMMS has been working since 2015 with the Integrated Communication Systems Group in the University's Faculty of Information Technology and Automation on planning new transmission methods for 5G, the next generation of mobile communications. Mobile devices and control units of the future will depend on 5G to support the Internet of Things and Industry 4.0.

The KOSERNA project has been developing a compact satellite receiving system for robust navigation applications since 2014 as is to last three years. As subcontractor to the University, IMMS is extending the frontend circuit and transferring the ideas researched in the predecessor project (KOMPASSION) onto a second frequency band. This extension means that the system is considerably more robust in the presence of parasitic or false signals and that the receiver can at the same time be smaller.

Working closely with the Institute of Biomedical Engineering and Informatics and the ZMN (Centre for Micro- and Nanotechnology) of the University, IMMS has researched a new three-dimensional array of sensors, actuators and electrodes in the 3DNEuroN project. This array has low power loss and low noise and is capable of both measuring and stimulating activity in nerve cells. The aim of the technology is to support the healing of damaged neural tissue. As a result of all this joint work, Ilmenau University of Technology was able in 2015 to pass a system on to the project partners in Finland (at the University of Tampere) and in Switzerland (ETH Zurich). Using the system, the partners have already been able in their initial experiments to achieve some of their neurophysiological aims upon electrical stimulation. The sensor and actuator electronics in the system were developed by IMMS.

Joint encouragement of young academics

One way, but not the only way, in which IMMS complements the TU's teaching is the range of industrial placements it offers. Another way is that various lectures and seminars are given by IMMS staff. Professor Sommer himself is, in his teaching role, involved not only in a national working party on teaching, the AG Lehre, but also, together with IMMS, in the Basic Engineering School, a practically oriented outreach of Ilmenau University of Technology. With its opportunities for practical experiment in close conjunction with industry and with such keynote events accompanied by industrial visits as the conference for alumni on the subject of Engineering and Computer Science – Application of Computers held in March to April 2015, IMMS acts both as teacher and motivator of students.

School-age children, too, receive the attention of IMMS and the University in the events of the Kinderuni (Children's University). In a lecture entitled "Wie kommen Punkt und Ton über Bits und Bytes in den Film? (How Do The Sounds and Pixels Get into a Film by Bits and Bytes?)", Professor Sommer involved more than 600 pupils aged between 8 and 12 in interactive experiments, enabling them to see the technology behind moving pictures and how many hours of film are reduced to a space smaller than a thumbnail.

IMMS regularly offers training courses and guided tours of the establishment. Here, MINT pupils are visiting the mechatronics laboratory for high-precision drives. Photograph: IMMS.

IMMS-specific encouragement of young academics

It is a special priority of IMMS to bring on the new blood in science. Again in 2015, the research staff at IMMS has been active in pursuit of this goal, inspiring and supporting undergraduate and Master's students in particular. School pupils, too, have been given insight into the work of IMMS by means of events and internships or by having their coursework supervised by IMMS professionals. The students at Ilmenau TU are the majority of those who come to the Institute, but they are joined by students from other universities at home and abroad in acquiring knowledge of methodology which is soundly based in theory and in linking this to its practical use. Young engineers from a variety of disciplines – biomedical, electrical or automotive, computer or mechanical engineering, mathematics, mechatronics and physics – are able to work on exciting scientific problems at IMMS and all receive individual supervision. The Institute also offers training courses and guided tours of the establishment. In all, the year 2015 saw 40 students working at IMMS either as interns or student research assistants or in association with the dissertations they were preparing for their BSc or MSc. The fact that the Institute networks so closely with industry provides the new generation of scientists with the opportunity to work on subjects of practical relevance where the results really matter.

IMMS has its own internationally competitive infrastructure, fully meeting industrial norms. The equipment supports the design of and experimentation on electronic and mechatronic systems, and underpins the Institute's research work and the preliminary processes necessary to systems verification. The fact that we attract so high a proportion of students from our own TU indicates how fruitful are our intensive pure research efforts. We think this is why highly motivated, high-flying students find their way to IMMS, and are delighted that they do. There are other ways in which IMMS supports and stimulates new academic blood: one is the Scientific Seminar, at which undergraduate and doctoral students present their work and any issues for discussion. The intense and lively academic exchanges here initiated cross subject borders, encouraging new connections to be made and new ideas to be considered.

Dipl.-Ing. Bianca Leistritz, doctoral candidate at IMMS "While I was reading for the German 'Diplom' in Mechatronics at Ilmenau University of Technology, I was already constantly on the lookout for practical and academic challenges. I worked part-time at IMMS for a number of semesters as a research assistant on a variety of topics including calculation scripts, experimental set-ups and the taking of measurements. Having had such positive experience at the Institute, I returned there after my internship overseas to research the fundamentals of air guidance elements operating during my degree dissertation.

Since that time, the subject for my doctoral research at IMMS has established itself as the Increase of Power Density in Electromagnetic Energy Harvester for Low-Frequency Broadband Applications. En route to this undertaking I had the opportunity of gaining experience and skills as a member of the scientific staff involved in a wide range of projects on various of the IMMS research subjects.

These included the development of (macroscopic) precision direct drives to meet a variety of needs and participation in the USENEMS project, simulating structures to enable the materials parameters of MEMS (microelectromechanical systems) to be determined. MEMS was also my focus in the GreenSense research group. I researched, developed and implemented MEMS which would supply energy to miniaturised sensor systems. At the same time I was working as a member of the PORT research group at Ilmenau University of Technology. There, the research concerned precision energy harvesters for autonomous sensor systems to be used in the automotive industry.

The idea of getting sensor systems to work autonomously in application settings with widely varying demands and of developing an associated automated design procedure for energy convertors is an idea I find exciting. With my doctoral thesis I hope to progress it considerably. Just as when I was working on my earlier subjects at IMMS I find that I benefit from the constructive conversations we hold as an interdisciplinary team and that they lead to innovative, eminently practical solutions. At the Institute there is not only this excellent collegial atmosphere, itself such a feel-good factor, but also the availability of excellent infrastructure and equipment to underpin my doctoral studies. Not only a wide range of software tools but also a full complement of measuring equipment is helping me to pursue my ideas by experiment."

Dipl.-Ing. Jun Tan, doctoral candidate at IMMS "I have been at IMMS since I started my internship with them in microelectronics. This was followed by my dissertation for the German Diplom (MSc equivalent) at the Institute and I received excellent supervision. I continued my involvement in different projects, so that I eventually found the research focus for my doctoral work. It is my aim to combine precision microelectronic low-power smart sensors with miniaturised RFID technology.

The first stages of this idea came to me when I was working on a project in which we were making a temperature sensor capable of measuring temperatures up to 1200 °C with the highest of accuracy for automotive applications. I was one of the members of staff who worked on a highly accurate reference voltage for the analogue-digital converter and a very precise amplifier. I published a related paper on Digitally Trimmable Wide Temperature Range 0.35-µm CMOS On-Chip Precision Voltage Reference at the Analog 2013 conference. When involved in the GreenSense project I shared in work on energy-autonomous sensors, developing an innovative low-power temperature sensor; patent has now been applied for. I went to Japan to present these results with the title A Low-Voltage Low-Power CMOS Time-Domain Temperature Sensor Accurate To Within [-0.1, +0.5] °C From -40 °C To 125 °C at the IEEE APCCAS 2014 conference and received the Best Paper Award. For me, this was not only a very happy moment but also confirmation that I am on the right track for my PhD, which I have been pursuing in the Admont project since 2015. There part of my work is on the development of wireless multiparameter biological sensor networks enabling biochemical data to be captured with no physical contact and thus under sterile conditions.

I find in IMMS a wide platform offering many opportunities to researchers and developers. From the first, I have had the wind in my sails at IMMS; not only the many interesting R&D subjects but also the space to pursue them, receiving at the same time every encouragement and support on both the matter and the means, have been a stimulus to my scientific development. I should like to point that it is a pleasure to work in our international team with its cheerful atmosphere. My colleagues support me all the way. I love analogue IC design. It is my belief that I am making great progress at IMMS and that I will be able to repay the Institute's support through my passion for analogue IC design."

Voices from industry and academia

Dr. Daniel Müller,

Head R&D ASIC, Sensirion AG.
Photograph: Sensirion AG.

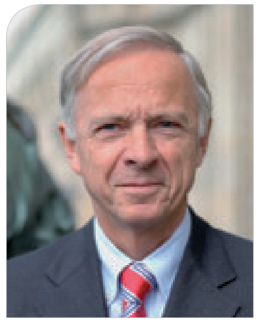
Dr. Daniel Müller, Sensirion AG

"Sensirion's business is unified sensor solutions for the automotive market, among others. We have worked together with IMMS to develop for a Tier 1 automotive manufacturer who is one of our most imporant customers a completely new feature which will be integrated into a new sensor ASIC. The product goes into mass production in 2016.

IMMS made available its SENT transceiver as soft intellectual property (soft IP) and adapted it to match our requirements. This IP is clear in design, comprehensible in its implementation and provided with documentation at the professional industrial level. It meets our expectations with the excellence of its functionality, area taken up and power consumed. It was supplied complete with verification environment and the necessary data for synthesis. Integration of the IP was simple and fast; IMMS provided the best of support. When the complete system on chip was evaluated, the IP was confirmed to be operating perfectly.

We are more than satisfied with the results of the collaboration and the collaboration itself, and wish to give particular mention to the great flexibility shown in response to our change requests, which received straightforward and at the same time completely professional treatment. This flexibility, together with IMMS' consistently pleasant and knowledgeable communication, played a major part in the success of the project. The entire collaboration was a highly successful example of knowledge transfer between academia and industry and we greatly look forward to opportunities to repeat it in future."

www.sensirion.com



Prof. Dr.-Ing. Erich Barke,

past President of Leibniz University, Hannover, where he was Head of the Department of Design Automation in the Institute of Micro-Electronic Systems until 2015. Member of the Scientific Advisory Board of IMMS until 2015. Photograph: LU Hannover.

Prof. Dr.-Ing. Erich Barke

"For a number of years up to 2015, I had a role in the scientific support of the staff at IMMS as a member of their Scientific Advisory Board. Since 2014, IMMS has been working jointly with my Department on the ANCONA cluster research project, which focusses on analogue coverage in nano-electronics.

Among the developments for which the Department I led at Hannover was responsible are (among other things) methods of researching the parameters by which this analogue coverage can be quantified. These need to be capable of indicating how completely all the relevant operational cases for an analogue circuit have been verified, and with what degree of certainty. The Erfurt branch of IMMS is involved in finding methods by which there can be automatic integration of, for example, parasitic coupling into the models at system level and into the methods by which the models can be efficiently simulated.

It has already been possible for us in Hannover to use design data from the IMMS ASICs after processing in the validation of our approaches. Reciprocally, the Erfurt staff have been able to make use of the knowledge they have gained by means of our efficient simulation methodology, which goes by the name of PRAISE. Not only the excellent collaboration in the project with its personal and professional exchanges but also the publication success we have together achieved bring me much pleasure.

Over and above this, my activity on their Scientific Advisory Board has enabled me to follow with interest the progress IMMS has been making in the blending of microelectronic and micromechanical methods to achieve a fully combined design system for MEMS. From the standpoint of design automation, the IMMS approach has so far been crowned with great success. The future of MEMS will only be secure if these systems can be developed and produced with the readily available aid of such comprehensive design methodology. Even if the application of the methodology will in principle be the task of commercial EDA companies, the contribution made to the solution of the problem by the pure research of such institutions as IMMS is not to be underestimated. In Germany, quite particularly, outstanding expertise on MEMS is to be found. The EDA companies, based mainly in America, can and must profit from this expertise, a fact which assigns to IMMS a cutting-edge role. On MEMS, the Institute has, namely, particular knowhow not only on general development but also on the specification and implementation of the necessary design methodology.

As IMMS continues along this route, I wish everybody much academic success and, on the business front, commercial prosperity."

http://www.ims.uni-hannover.de/

Thomas Freitag,

Development Manager
Melexis Microelectronic Integrated Systems.

Photograph: Private source.

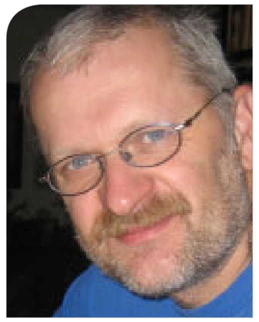
Thomas Freitag, Melexis

"For many years, IMMS has been supporting us in the development and refinement of our ICs, among them those for LIN-based regulation of RGB LEDs so that the lighting of car interiors is flexible and economical.

Together, IMMS and Melexis worked in 2015 on an extension of this LIN RGB product family. The new development provides advantages to our customers, one of which is that it requires only one IC to control two RGB LEDs. It also has more memory space available. Our colleagues at IMMS helped in various ways. These included undertaking the verification of the new designs and modelling the behaviour of the environment for us in mixed signal hardware description languages. Now that the early versions have been successfully quantified, IMMS is currently working on a special test set-up that will check the parameters of the new designs, which have already gone into manufacture.

It is our intention to collaborate again with the Institute in the future, continuing to rely on its skills. We are more than satisfied with the IMMS way of working, flexible and outcome-driven – do keep it up!"

www.melexis.com



Prof. Dr. Peter Holstein,

Head of Strategic Development, SONOTEC Ultraschallsensorik Halle GmbH.

Photograph: Private source.

Prof. Dr. Peter Holstein, SONOTEC

"SONOTEC was in search of a partner with whom to develop an innovative digital ultrasonic testing device. The purpose of the device is to detect leaks so that maintenance needs can be anticipated; it is a first-time combination of innovative sensors and signal measurement technology, smart software and user-friendliness. To develop such a device, deep understanding of digital architectures and of signalling behaviour in acoustic measurement systems is required. We were aware of the IMMS background in audio-signal processing and related hardware development because of the Institute's activities on the industrial cooperation and technical transfer scene, together with the external impact of these activities. Having realised the technological significance of IMMS' work, we found in the Institute all the necessary skills – among them model-based development, electronic systems design and experience in the digital processing of acoustic input signals together with embedded computing skills and full understanding of manufacturing operations. IMMS has now designed the digital components of the hardware to be used in our new tester. The signal processing performance achieved is largely based on FPGA technology, a field in which IMMS has excellent references.

Our joint work with IMMS went off perfectly. The cooperation was unbureaucratic; the work outstandingly easy to plan and to coordinate. I should like to single out the efficiency of the iteration cycles. Any progress made was immediately communicated. It all worked out so well largely because of the close and intensive personal cooperation between the IMMS and SONOTEC colleagues.

New products and new technologies are subject all the time to ever more challenges, for example in the context of Industry 4.0 with all its opportunities and issues. The IMMS style of work and quality of results inspire us to plan longer-term cooperation with the Institute."

www.sonotec.de

RESEARCH SUBJECT

ENERGY-EFFICIENT AND ENERGY-AUTONOMOUS CYBER-PHYSICAL SYSTEMS

IMMS has been working on a "smart jacket" with knitted electrically conducting switch patches since 2015. The Institute is developing the integrated electronic components, which securely transmit a switching command by radio to one or more receivers placed up to 30 metres away.
Photograph: IMMS.

Highlights of 2015 in our energy-efficient and autonomous systems research

CPSs (cyber-physical systems) consist of linked embedded electronic hardware/software components communicating via data networks and interacting with the real world by means of sensors and actuators. CPSs form the basis of the "Internet of Things and Services" and for future implementations of complex and distributed control and automation systems to bring forward industrial production ("Industry 4.0") and energy management ("Smart grid"), amongst others.

As CPSs will thus contain a huge number of components and will be massively distributed, energy- and resource-efficiency of those systems are of great significance. Our research therefore focuses on the development of highly energy-efficient microelectronic and embedded systems for the acquisition, processing and communication of measurement and control data. For this purpose, we investigate and create hardware and software solutions for wired and wireless sensor and actuator networks, particularly regarding aspects such as real-time capability and energy-autonomous operation.

Best paper award for work on methods of computer-aided verification

Together with its research partners, the Institute received the Best Paper Award at the Forum on Specification & Design Languages (FDL 2015) in Barcelona, Spain on 16.09.2015. The award was for its presentation of Temporal Decoupling with Error-Bounded Predictive Quantum Control, a paper describing work done in the ANCONA (Analog Coverage in Nanoelectronics) cluster project which is following up particular aspects of earlier research projects such as GreenSense. There are another five universities or research establishments besides IMMS in the cluster. IMMS is focussing on computer-aided verification methods which will improve and greatly accelerate the design of mixed signal (analog-and-digital) circuits. Through such circuits will come the realisation of such visions as the Internet of Things and Industry 4.0. Up to now it has been almost impossible in anything but an experimental set-up to test the interaction between the system components and any parasitic currents. For that reason, the project partners are working on computer-aided procedures which will ensure that the reliable functioning of complex systems has been verified even at the design stage. The specific development focus of IMMS is on design methods which will, among other things, integrate parasitic coupling into system models and enable the coupling phenomena to be efficiently simulated. For such complex simulation activity, various simulators frequently have to be combined together because their synchronisation is a significant factor in how they perform. The paper points out one potential method of reducing the resources required for the synchronisation and making the task more manageable.

Georg Gläser, IMMS, at FDL2015 in Barcelona. The paper presented by Mr. Gläser on methods of computer-aided verification was given the Best Paper award. Photograph: Lukas Lee, Leibniz University, Hannover.

IMMS receives the iENA silver medal for energy-efficient solutions in integrated circuits

On 16 December 2015, IMMS was honoured with a silver medal in the competition associated with iENA 2015, the 67th international trade fair on "Ideas, Inventions, New Products". The medal was for developing an electronic delay circuit in CMOS technology. A presentation on this successful work was given by the inventors, Benjamin Saft, Eric Schäfer and André Jäger, during the award event at Ilmenau University of Technology. The delay circuits had been created at IMMS in the GreenSense research project and have been included and tested in prototypes of a microelectronic energy harvesting evaluation circuit.

The IMMS invention has made a four-fold improvement in the ratio of delay time to energy used when compared with previous state-of-the-art CMOS thyristor delay elements. The new approach means that longer delay times are possible with the same energy consumption or less area is needed for the same delay time. Because of these properties, developers and manufacturers of ASICs or MEMS can make use of the new delay elements when developing ultra low-power circuits to install in energy harvesting modules or micro sensor-actuator systems intended energy-efficient and/or autonomous bioanalysis and Industry 4.0 applications. The inventions are currently being further developed at IMMS in follow-on projects such as ADMONT.

The Silver Medal for energy-efficient solutions in integrated circuits being presented to the inventors, André Jäger, Benjamin Saft and Eric Schäfer (r. to l.) at the awards ceremony on 16th December 2015 by the iENA organisers (left: Mr. Könicke of AFAG Messen). Photograph: IMMS.

Start of RoMulus Project

RoMulus is the acronym for Robust Multisensors for status monitoring in Industry 4.0 applications. The programme was launched in October 2015. In it, experts from research and industrial settings are exploring new technologies and design methods which will support production of systems combining multiple sensors and offering robustness and energy-efficiency. Without such systems, status monitoring and quality assurance are unthinkable for digitised production processes. With them, the trail is blazed for Industry 4.0, the fourth industrial revolution. A further aim of the current work is to achieve systematic design and economical manufacture for these systems.

Here, the Institute is, firstly, intending to extend the design tool developed in the MEMS 2015 project for acceleration sensors. The tool, which can already design uni-dimensional sensors automatically, will then be able to do the same for 2D and 3D sensors. The development work will also assist in ensuring parasitic influences from the environment of the sensors are taken into account during the design process.

Secondly, IMMS is working on new ultra low-power circuits for RFID multi-sensors to be used in industry. The overall aim of this project is a low-power sensor and IP platform which will enable SMEs to have access to high-tech sensors in the Internet of Things.

Funding comes from the BMBF (Federal German Ministry of Education and Research). Reutlingen University is the coordinator.

Smart Jacket project begun

Since January 2015, IMMS has been involved with Strickmanufaktur Zella GmbH, a knitwear factory, in the development of knitwear, especially cardigans (Smart Jacket), with integrated radio controls that are combined with knitted switch patches. The aim is to enable people with physical disabilities to switch on or operate things like lights, machines, doors, furniture or games indirectly, by simply moving an arm against their own body or against a solid object like a chair. People who are unable to operate switches by hand need material that stretches onto their body shape to ensure that they can actually feel they have made the switch work.

When somebody presses a switch patch, made from electrically conducting polymer yarn, the integrated electronics securely transmits a switching command by radio to one or more receivers placed up to 30 metres away. The Smart Jacket has to be washable and it must not be necessary for the electronics to be removed before washing. There are further constraints: the battery for the electronics needs to last from two to three years in normal use. Also, any switching must be exclusively the result of a mechanical action and only triggered when the clothing is being worn. There are no such systems commercially available as yet. The knitted switch patches, the wiring of the cloth, the cloth care requirements and the design of the jacket are all the responsibility of the knitwear factory. IMMS is responsible for planning, design, development, and integration of the electronics (both hardware and software) for the cloth as well as for the receivers that have special switching actuators contained in them. In association with these tasks, the Institute is working on solutions for the power supply, radio link, and configuration as well as functional safety and communication security.

The IMMS model demonstrating electric car mobility which won the Best Demo Night Award at the Conference on Design & Architectures for Signal & Image Processing (DASIP) in Krakow, Poland, on 23.09.2015. The model and work entitled Wireless Sensor Networks for Traffic Applications: Challenges and Solutions were also fully tested by visitors to the Lange Nacht der Wissenschaften (evening science festival) in Erfurt on 6 November. Photograph: IMMS.

"Fast wireless" project begun

At the basis of a wide range of innovative applications is real-time capability for mobile data transmission. Examples of these applications are car-to-car communication, inter-machine communication and the "tactile Internet". All require the interaction of a huge number of sensors, which must have very short signalling times with delay or latency of only milliseconds, and data and signal connections that are absolutely reliable so that there are no outages. No wireless technologies to date are up to these requirements. One response has been to develop standards like LTE[1], mainly for the high capacity expected.

In this context, the "fast wireless" project is exploring, developing and evaluating basic technology for fifth generation (5G) mobile communication with minimal latency so that mobile devices can network in real time with control units. A major focus is on developing transmission systems and scenarios that do not conflict with the principles of low latency and high reliability. IMMS is defining the requirements for real-time operating systems to work this future type of transmission, is supporting the other partners in the project on the specifications of suitable interfaces between the communication layers and is developing components which will permit latency-critical elements to be partitioned into the hardware and software parts. It is intended to include the outcomes of all this research on a demonstrator platform which IMMS will develop. For the platform, the Institute is specifying application scenarios and implementing the algorithm worked out by project partners.

1 **LTE** *Long Term Evolution, 4th generation mobile communication standard (3.9G)*

sMobiliTy project culminates with Best Demo Night Award

On 23 September 2015 at the Conference on Design & Architectures for Signal & Image Processing (DASIP) in Krakow, Poland, IMMS presented its work on Wireless Sensor Networks for Traffic Applications: Challenges and Solutions and received the Best Demo Night Award. In this demonstration in parallel to the closing event of IMMS' participation in the Smart Mobility in Thüringen research project, the Institute set up a car racetrack supplied with sensors to show the DASIP participants its results from the project. The simple-to-install wireless sensor system will be a means of progressing electric car mobility.

On the 6 November 2015 at the Lange Nacht der Wissenschaften, a local science festival in Erfurt, visitors were able again to test out the prize-winning demonstrator track.

Involvement in the eMobilityCity network

IMMS has been active in the eMobilityCity network since 2015. This is a network in which skills are shared and innovations made for electric car mobility in Thüringen. It unites partners from the four joint Thüringen projects with the names sMobiliTy, Smart City Logistik, eTelematik and EMOTIF. In the network, IMMS provides the scientific support for the wireless sensor platforms which have been developed for tactile roads and acts as coordinator for the continued activity of all the partners in the use of the systems in traffic.

The prototype smart current clamp refined by IMMS of which the Institute helped produce 40 examples in 2015. The prototype version is now being used and tested by IMMS' partner InduSol in the preparations for mass production. Photograph: IMMS.

The S4ECoB project concluded

In 2015, the S4ECoB (Sounds for Energy Control of Buildings) project was duly completed with IMMS having developed an embedded platform for a system processing audio signals. This system will support greater energy-efficiency in the building management of the future. For building automation in large public buildings to run as efficiently as possible, it is important to know how many people are present at any one time in particular areas of an establishment. The system (S4ECoB) developed in the project sees microphones distributed over a network to pick up the sounds around them. The complex system is able to analyse the number of people in a part of the building from the sounds made, regulating heating and lighting accordingly.

IMMS developed the embedded platform that processes the acoustic signals from 3 x 8 microphones, creating suitable hardware and implementing the software components designed. The Institute was also responsible for the design and implementation of the communications architecture between the components. The innovative architecture and the new methods used in the hardware and software implementation have proved to be the key to an embedded signal processing platform with the virtues of low energy usage, high performance, flexibility and low costs.

Smart current clamp prepared for mass production

The current clamp developed by IMMS and presented at embedded world 2015 is a small, mobile device which will work for 14 days on end, registering and evaluating parasitics on communication wires while machinery is operating. The current clamp helps users to make their own diagnosis of sources of parasitics, decide on the level of disruption and store data for later analysis. It thus has far greater capability than any previous devices or procedures for such analyses. Among the elements of the work done by IMMS were a range of tests on magnetic circuits, application of efficiency criteria so that the right hardware, analogue adaptive circuits and software elements could be selected, and the development of software. IMMS also optimised the energy consumption of the entire system and designed the casing. Now that the partner industrial company, InduSol, is preparing to take the current clamp to mass production, IMMS has reworked the prototypes. The Institute supervised the manufacture of 40 devices in 2015 which are now being used and tested at InduSol.

ANCONA

Computer-aided verification methods – fresh impetus for Industry 4.0 developments

IMMS is at work on ways of automatically extending models of mixed analogue-and-digital circuits at system level so as to identify critical scenarios. FPGAs such as the Virtex7 demo board shown here are used for system simulation. Photograph: IMMS.

Objectives

At the basis of all the smart systems which can function as part of the Internet of Things and of all the high performance applications needed in Industry 4.0 lies the technology contained in complex, highly integrated micro-electronic chips. The System-on-Chip (SoC) technology compresses numerous elements and functions, both analogue and digital, into the narrowest of space, crowding together sensors, actuators and signal processing. Any errors in the design of the integrated circuits may impact on turnover to the tune of several hundred million dollars. They can cause costly downtime and, far worse, highly expensive product recall, repair and replacement. In order to keep such risks to a minimum, designers strive to recognise any faults as early as possible in the design process.

There is a further imperative: to design yet smarter and thus even more complex systems to meet new demands in the context of Industry 4.0. Research is focusing on the development of many new system components for the future. How these will interact with current methods can as yet only be tested in experimental setups. In anticipation, the ANCONA project partners are working on computer-aided procedures which will provide reliable testing of complex systems even at the design stage and prove their functionality. These procedures are intended to simplify and significantly accelerate the design process for mixed analogue and digital circuit systems. They will boost innovation potential and give their user a competitive edge. The specific development task of IMMS is to focus on design methods which will, among other things, integrate the coupling of the components into system models and enable the models to be efficiently simulated.

Pre-existing technology

There are many established methods of evaluating the design of the digital components of a system. These include the automatically generated random test signals which are part of the state of the art of Universal Verification Methodology. There is also the possibility of calculating how well the tests have monitored the system behaviour, for instance by comparing the number of system states tested with the number of possible system states.

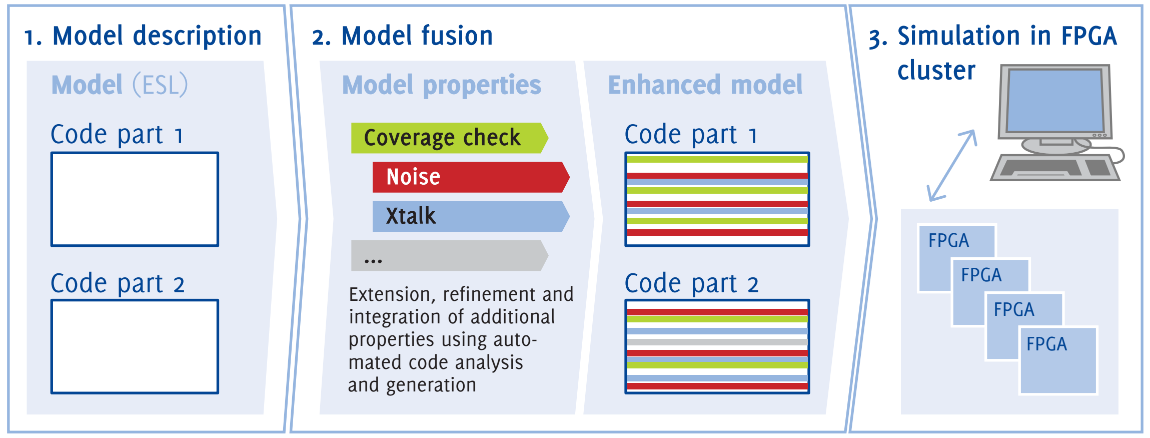


Fig. 1: The IMMS contributions to the ANCONA project in brief: a system model extended automatically by further properties, and simulated with the aid of FPGA-based hardware accelerators. Diagram: IMMS.

However, there is a dearth of such methods for the design of systems which use analogue or mixed signals. Such systems may combine purely digital functions with analogue sensors and actuators. For these, it has not been possible so far to create test cases automatically or to evaluate the quality of the verification objectively. In consequence, it has always been necessary to take the design of newly developed mixed analogue and digital components (intended for highly complex systems) to the prototyping stage and then to test the component interactions in the experimental prototype. In this method an additional challenge is the resource-consuming nature of the simulation runs. In digital systems, hundreds of test cases are not expensive in run time, but that is well-nigh impossible in the analogue context. The computing time needed for simulating an individual test case could range from a few minutes to many hours.

The conventional work-around for these huge simulation times is to take an idealised model which will give a "good enough" representation of the circuit behaviour. This method does at least enable the functions of a chip to be verified at the system level. On the other hand, there is no representation of complex interactions which are quite capable of disrupting or even destroying a system. Total chip breakdown can result from temperature changes or certain effects of noise or parasitic coupling due to power supplies.

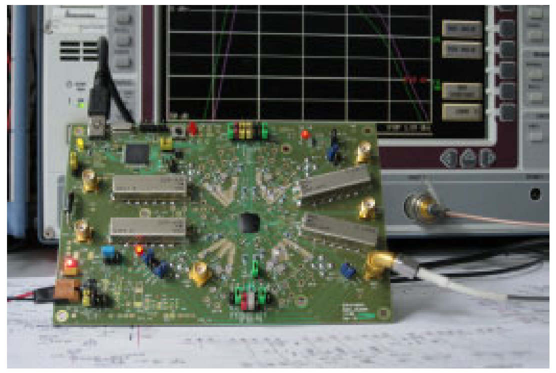


Fig. 2: Evaluation board normally used as a finished prototype to characterise a system. Photograph: IMMS.

IMMS approaches to computer-aided verification

For the necessary new procedures, IMMS is mainly focusing its efforts on the approaches illustrated in Figure 1. Firstly, the Institute employs the models which have been generated during the design process in parallel to the actual circuit so that they can be extended automatically by any additional effects. The influence of the additions can be evaluated in this way and any critical scenarios identified. Secondly, IMMS is working on the development of hardware accelerators using FPGAs[1] so that the system performance can be more efficiently evaluated and simulation time brought within reasonable bounds.[2]

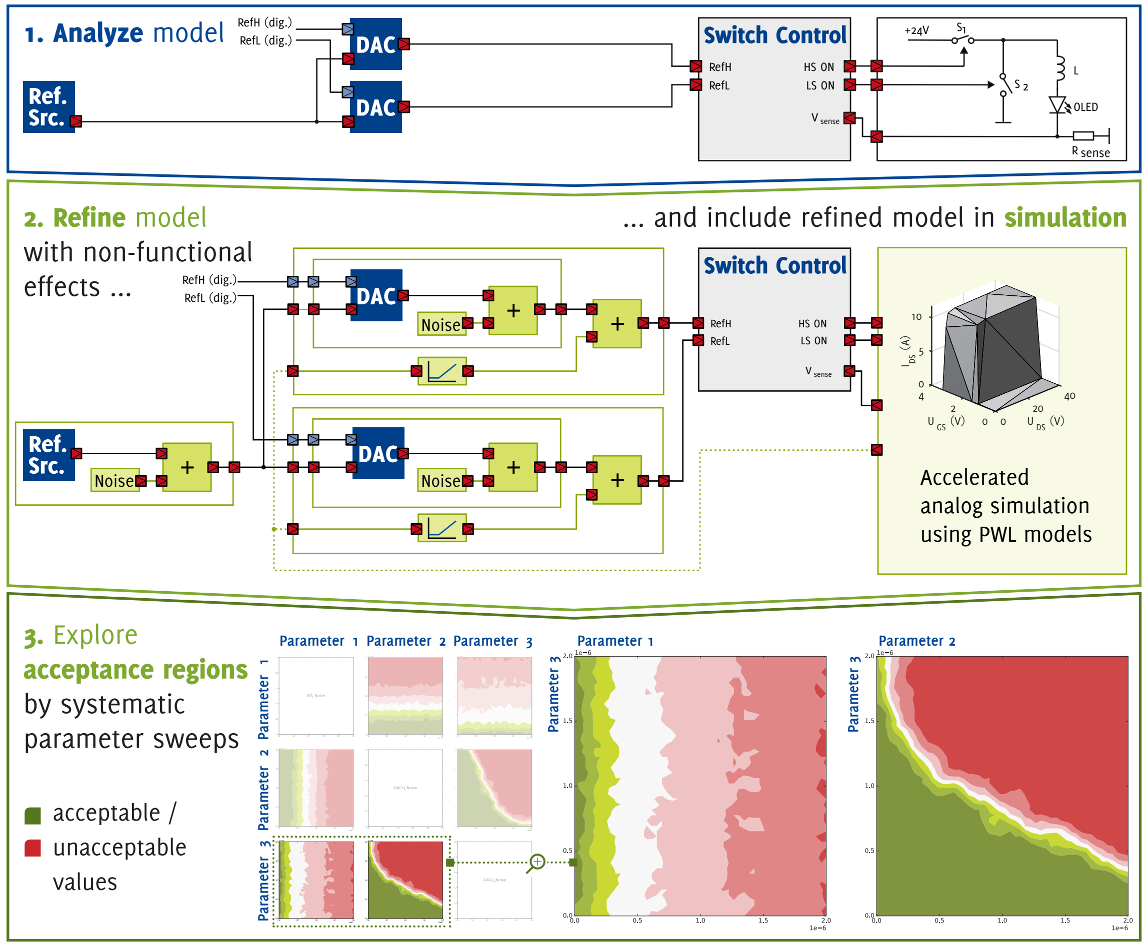
Automatic extension of models at system level for identification of critical scenarios

When analogue and mixed-signal systems are being designed, it is conventional to design virtual prototypes, i.e. models for simulation of the SoC, to check and guarantee the system functionality.

Figure 2 shows an evaluation board commonly used to characterise a system when it has already been manufactured as a prototype. It is usually only at this stage that the system comes under the influence not only of its own specified functional properties but also of other factors which are extrinsic to the functions. The quantities describing these factors may be the system's own power take-up and/or interruptions of power supply and/or the analogue behaviour of signals conceived as purely digital. Such factors may lead to disturbance of the system's behaviour or even

1 **FPGA** *Field Programmable Logic Array – a component capable of using logic to carry out any number of freely selected digital functions.*

2 *Cf. "Automatic Annotation of Properties to ESL SystemC Models and Accelerated Simulation", Georg Gläser, Eckhard Hennig, Forum on Specification and Design Languages (FDL), 2015, 14 – 16 Sept., Barcelona/Spain.*



to a complete crash even though verification has taken place using virtual prototypes.

Though it is actually possible to integrate the quantities for these external influences into the verification, the process is extremely unwieldy and time-consuming: given five factors and their possible combinations in one small component, there will be 31 combinations to take into account and to implement in the code of the model of the virtual prototype. For the verification, it would also be necessary to create a model of the whole system in every case for each relevant combination. As this shows, immense resources are needed for implementation and maintenance, increasing intensely with the number of factors. As it is rarely possible to assess in advance which quantities will disrupt the behaviour, the initial phase will be burdened with the need for investigating even more of the possible quantities.

It is to meet this challenge that IMMS is making its first contribution for the ANCONA project (see Figure 3). Any existing model-code is refined automatically using automated code analysis and code generation, then the system is analysed for critical configurations. This method protects the system against the disruptive influence of parasitic couplings even in the earliest design phases. Such situations cannot at present be observed before the design is complete and/or the chip manufactured.

Fig. 3: Process by which regions of acceptability are determined for the system: the parameters added by annotation are investigated to permit discovery of critical scenarios. Diagram: IMMS/University of Hannover.

Evaluations of the new procedure have already taken place, for instance in respect of a design made in the EROLEDT research project. Here the need was for the stability and operational reliability of a specialised driving circuit for organic light emitting diodes (OLEDs) to be investigated. The idealised system model already existing was taken as the starting point (see Figure 3 (1)). An analysis of the influence of interference on reference voltages was required, i.e. it was necessary to extend the DAC models which might be affected by such interference.

The process of refinement is shown for demonstration purposes in Figures 3 and 4: first the code for the model of the DAC is analysed using a program developed at IMMS on the basis of libClang. The details of structure and function of the model thus obtained

Template

```
SC_MODULE(${target_name}) {
public:
${str_portlist}

private:
  ${base_name}* base_class;
  sca_tdf::sca_signal<double>
    ${parameters['port']}_tmp;

  noise_gauss*   noise_src;
  add*           noise_adder;
  sca_tdf::sca_signal<double> noise;

public:
  SC_CTOR(${target_name}) {
    base_class = new ${base_name}("base_class");
    base_class->${parameters['port']}
      (${parameters['port']}_tmp);
    ${str_connectionlist}

    noise_adder = new add("noise_adder");
    noise_adder->in1(${parameters['port']}_tmp);
    noise_adder->in2(noise);
    noise_adder->out(${parameters['port']});

    noise_src = new noise_gauss("noise_gauss",
      ${parameters['variance']},
      ${parameters['mean']});
    noise_src->out(noise);
  }
};
```

Generated wrapper

```
SC_MODULE(TargetModule) {
public:
  sca_tdf::sca_in<double> in;
  sca_tdf::sca_out<double> out;

private:
  Base *base_class;
  sca_tdf::sca_signal<double> out_tmp;

  noise_gauss    *noise_src;
  add            *noise_adder;
  sca_tdf::sca_signal<double> noise;

public:
  SC_CTOR(TargetModule) {
    base_class = new Base("base_class");
    base_class->out
      (out_tmp);
    base_class->in(in);

    noise_adder = new add("noise_adder");
    noise_adder->in1(out_tmp);
    noise_adder->in2(noise);
    noise_adder->out(out);

    noise_src = new noise_gauss("noise_gauss",
      0,
      0.0);
    noise_src->out(noise);
  }
};
```

Fig. 4: Model extension using a template engine: additional data added into a pre-existing template. Diagram: IMMS.

enable a wrapper which represents the original property (in this case, added noise) to be provided. This wrap is generated for the model by filling gaps with text, as is shown in Figure 4. A pre-defined code is adapted to take account of the analysis data and added on to the existing model.

The implementation of this step uses text templating, a procedure in web design. In this procedure, a given template is automatically extended by additional elements and data. In the present case, the template is model code representing additional model properties. A library of various templates has been created at IMMS and is being constantly added to. The process of annotation can be repeated for various property templates kept in the library, to enable the model to be extended by yet more factors (see Figures 3 (2) and (3)).

The next step is to integrate the automatically extended model into the simulation of the system as a whole (Figure 3 (2)), so that the parameters of the effects of the additional factors are also considered. Various simulations are run in which the fuller set of parameters is varied and in each case the resulting system behaviour observed. In this way it is possible to establish ranges for parameter values associated with satisfactory outcomes. From the size and nature of these acceptance regions, illustrated in Figure 3 (3), the system architect can establish new parameter specifications and test-cases for the verification. The method enables the design risk (and danger of chip malfunction) to be minimised.

Hardware-accelerated simulation of mixed analogue-and-digital systems

It is typical of system verification to carry out many long cycles of simulation. To enable more efficient parameter studies to take place so that regions of acceptability can be identified, there is a need for more rapid simulation runs. FPGA-based hardware accelerators are now established in many fields of application. In that of digital design such FPGA prototypes are often used for the development of software before the actual chip is present.

To date, there are no analogue FPGAs available in useful dimensions. Admittedly, tiny structures such as individual amplification blocks can be included in certain special chips on the basis of FPGAs. However, this is not a feasible approach for the prototyping of large systems which combine many different elements. As every chip contains many hundreds of different blocks there would be a need for at least a similar number of prototyping platforms, which could not be justified commercially. Not only this, but the parasitic effects of the platforms would greatly disrupt the observations.

Therefore, within the ANCONA project, IMMS is taking a new path and using standard industrial tools for high level synthesis[3] (the Cadence C-To-Silicon Compiler, for instance) to represent models of mixed analogue-and-digital systems on conventional FPGAs – i.e. on purely digital hardware.

3 **High-Level Synthesis** *Process for representing software code on logical functions to enable its implementation in hardware, for instance in FPGAs.*

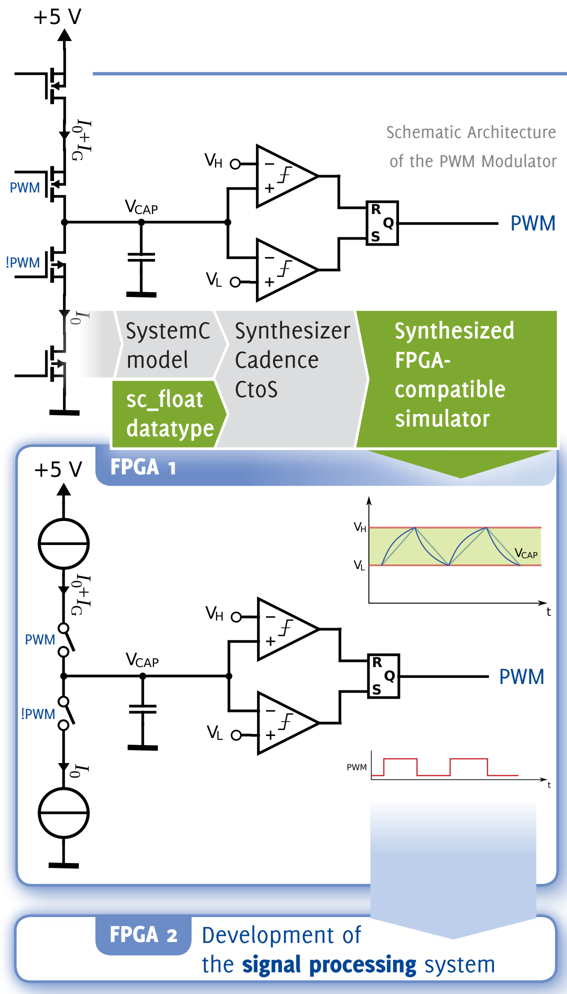


Fig. 5: Simulation of a mixed-signal system using the FPGA method. Diagram: IMMS.

This mapping method has already been employed at IMMS in the development of a high-temperature sensor. The sensor interface with a PWM[1] modulator shown in Figure 5 was investigated for its response to current leakage due to heating effects. For the purpose, the linearity of the conversion characteristic was established as would be the case with an ADC. The simulations necessary take an extremely long time. One attempt led to the estimate of several days at normal computational speeds.

An FPGA prototype (Figure 5) is now being employed to assist in such cases: A model of the circuit in SystemC is transferred with the help of special floating-decimal-point data types into a hardware accelerator which has been specially adapted in terms of resource consumption, speed and accuracy. In contrast to standard C++ data types, these data types, which have been developed at IMMS as part of the project, offer the option of arbitrarily adapting the values in the internal register so that the performance of FPGA-based simulation attempts is considerably enhanced. By this means, the model has been synthesised into an FPGA prototype, simply through slight modification of the model code and implementation of a differential equation solver.

A schematic diagram of the prototype is given in Figure 5. The model of the high-temperature sensor interface has been created on a Virtex-5 demo board with the algorithm for calibration and evaluation of the measured values present on a second FPGA, which had already been designed at an earlier stage of the development. The feasibility study here shown became the foundation of more rapid simulation episodes.

1 **PWM:** *Pulse Width Modulation – the data for the value constituting the message is coded in the duty cycle of a digital signal.*

Conclusions and Outlook

For the project, which aims to ensure the reliability of the design of today's microelectronic systems, IMMS is contributing crucial building blocks. The Institute received in conjunction with its research partners the Best Paper Award at the Forum on Specification & Design Languages (FDL 2015) in Barcelona, Spain for its presentation of Temporal Decoupling with Error-Bounded Predictive Quantum Control.

The second half of the project period, which runs until 2017, will be devoted to further development and integration of these contributions. There will be extension of the annotation of properties and extension of the methods successfully developed in SystemC to other modelling languages, such as VerilogAMS. More work is also to be done on synthesising these models into an FPGA for accelerated simulation purposes. Work will continue on optimising the estimation of acceptance regions for the design, where necessary with adapted algorithms to cut computation time even further and speed up the design and verification process.

IMMS will be incorporating the new-style verification method into all its research projects as an enhancement of the quality of designs made in those projects. Knowledge gained from this will be fed back into optimisation of the new method.

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Federal Ministry of Education and Research

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HoTSens
Development, Test and Characterisation of ASICs up to 300°C

Setting up the testing station with integrated cooling for complete semi-automated wafer testing up to 300 °C. Photograph: IMMS.

Objectives

For today's increasingly complex machinery and equipment to be operated safely with the highest possible efficiency in their use of resources and energy, it is essential that the state of each device and process be monitored at many points simultaneously with high speed and complete accuracy. The nearer to the process is any sensor and signal-evaluating equipment, the less interference there will be, and the more exactly can the signals be registered and processed. However, bringing such a system closer to the process means that it will need to withstand ever higher temperatures.

For these reasons, IMMS and its partners in the HoTSens project are developing an integrated systems solution which has sensors and electronics combining to function reliably in industrial plant and machinery at temperatures as high as 300 °C, under high pressure and in unusual climatic conditions. To date, for use at maximum operating temperatures up to 225 °C, there have been specialised micro-electronic ICs available. The sensor system module with integrated high-temperature electronics which is now needed will have to be able to amplify and calibrate the primary signals from a combined pressure and temperature sensor, processing them sufficiently to compensate for any potential error in the pressure signal. It will be a first-time system solution, offering exchangeable, standardised detector modules for use under the extreme conditions described.

IMMS has developed certain ASICs which are specific to the system and has tested and characterised them. For the purpose, the Institute has designed, constructed and successfully used a new test set-up with an integrated cooling system. This permits the wafer to be completely tested semi-automatically up to 300 °C.

Design of the high-temperature ASICs

Taking a variety of approaches, IMMS developed a variety of ASICs intended to process the signals from pressure sensors installed in ambient temperatures of up to 300 °C. By taking measurements on test structures, the Institute has characterised transistors at wafer level up to this temperature. Model circuits for the necessary components have been produced on the basis of these approaches in collaboration with X-FAB AG. Earlier models had characteristics capable only of temperatures up to 250 °C. In the new work, the basic analogue circuit structures for the amplifiers, voltage regulators and current mirrors have been modified so that there is very little current leakage and dependency on temperature, even for the range above 250 °C is much reduced. Symmetrical transistor structures have been laid out for positioning in areas of similar temperature, which will mean that they behave for practical purposes identically.

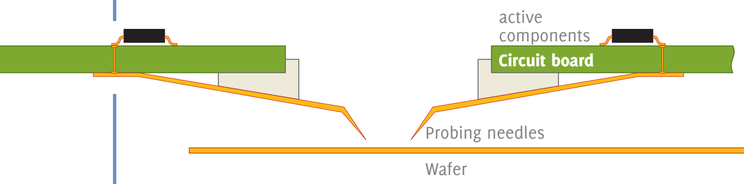
All the circuits have been designed to be thermally de-coupled and to be complemented by an additional, spatially separated circuit which has an input control, a high-voltage transistor and a diode protecting it against polarity reversal. The ASICs have been manufactured using X-FAB AG's XI10 SOI (Silicon-on-Insulator) technology, which is capable of use in temperatures up to 300 °C.

Challenges to be met by the test structures, state of the art

The ever greater challenges described here for the integrated sensors and signal evaluation electronics are challenges, too, for the testing of ASICs at wafer level. The standard circuit boards for wafer testing are needle probecards made basically of epoxy resin and will not stand temperatures above 175 °C. Even the other (much more expensive) materials for use in these boards, such as polyimide and Teflon, hit their temperature limit between 220 °C and 280 °C when used long-term.

For the high-temperature wafer test, it is common on the one hand to use ceramic probecards capable of sustaining more than 300 °C . On the other hand, probecards made of the materials approved for use up to 280 °C can be placed directly over the wafer or with an additional temperature shield in the form of an air-filled chamber. In a few cases, this type of chamber is flooded with cold air to achieve an additional cooling effect. In most cases, the electrical connection from the probing needles to the measuring instrument is made by long, insulated cables. This achieves spatial separation of all electronics from the vicinity of the needle card and the test. In consequence, the ASIC may be loaded with much too high an electrical capacitance due to the length of the wiring. For this purpose, a chip is not necessarily laid out appropriately and so the type of construction described is largely used on single building blocks such as transistors. In any other situations, the experimenter must take into account that the construction may well cause false readings.

Figure 1: Schematic of a classic needle probecard with active components for measurement on wafer. Diagram: IMMS.



The idea of adequate distancing as a solution for the high-temperature wafer test in the HoTSens context was discounted as the ASICs here being developed are too much influenced by the measurement conditions. Their driving capability is inadequately configured for these. By implication, the test conditions would not reflect the intended future sphere of use. So the circuit board and electronics had to be positioned close enough to the ASIC. This meant that the conditions surrounding all the active components which were to be positioned directly on the board for the HoTSens chip testing had to be taken into account. As these components include such things as an operational amplifier with a conventional upper temperature limit of 85 °C, it was necessary to achieve thermal de-coupling from the high temperature (300 °C) test environment.

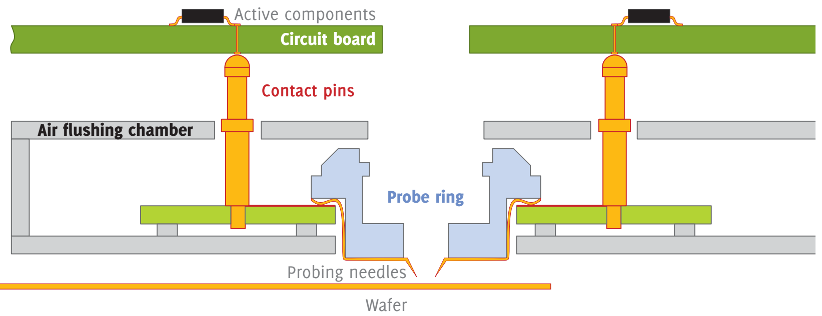
The IMMS solution for the high-temperature wafer test

To achieve exact measurement and characterisation of the features of the ASICs, IMMS has combined the procedure for the standard wafer test (Fig. 1) with that of the high-temperature wafer test, constructing the apparatus for the purpose. This makes contact with the wafer, sends the signals from it to a circuit board which includes evaluation electronics and then to a PXI strain gauge module, at the same time protecting the board and electronics from excessive temperatures with an air flushing chamber (Fig. 2).

Cooling of the PCB and signal evaluation electronics

The circuit board is made of standard, inexpensive material, a bond of epoxy resin and glass fibre fabric (class FR4), which becomes unstable at 170 °C, a phase transition temperature for glass (Fig. 3). To protect the board from the temperatures obtaining on the wafer (300 °C), an air flushing chamber was designed (Fig. 4). The choice of width, 4.5 inches, was influenced by the standard dimensions of probecard holders. The tank material selected was paramagnetic stainless steel 1.4305 as this has advantages over other metals. If aluminium or copper had been selected, thermal conductivity would have been higher, thermal expansion greater and rigidity less. The steel chamber is 10 – 20 times less conductive, 1.5 – 2 times less expansive and 2 – 3 times more rigid, thus providing an ideal barrier between the hot wafer and the cold circuit board. The barrier effect is reinforced by connecting a cold coolant gas to flush the steel chamber, flowing at approx. 25 °C to cool it actively.

Figure 2: One of the IMMS approaches to high-temperature testing at wafer level with a thermally de-coupled circuit board. Diagram: IMMS.



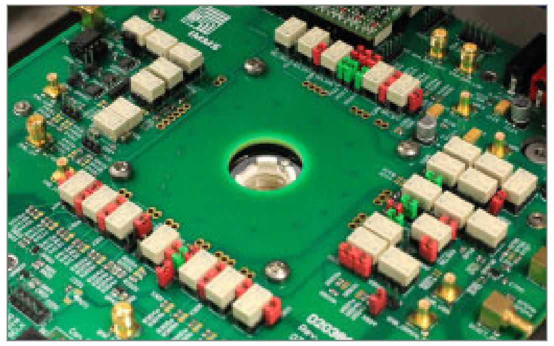


Figure 3: Circuit board with the necessary signal evaluation electronics. Photograph: IMMS.

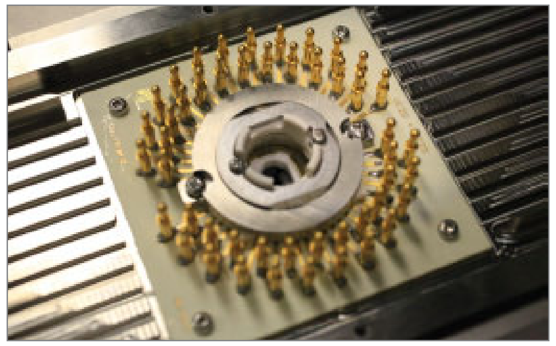
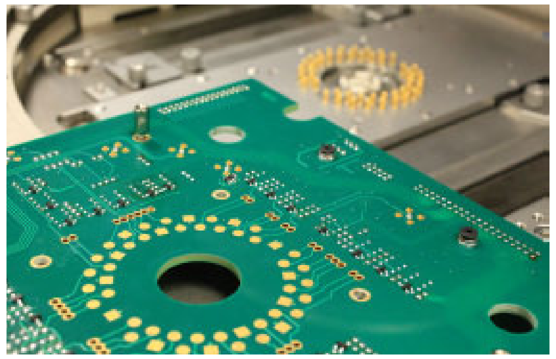


Figure 5: Ceramic board with probe ring to sample wafer and send signals to the circuit board. Photograph: IMMS.

Electrical contact

So that there is a reliable electrical connection between the circuit board and the wafer, it is necessary to create a path for the signals through the steel chamber. IMMS has designed and placed in the flushing chamber a ceramic circuit board in aluminium oxide with a glass transition temperature of much higher than 300 °C (Fig. 5). Though aluminium oxide with its electrical resistance of $10^{12}\ \Omega\cdot$m serves as an excellent insulator in the relevant temperature range, it is also an excellent thermal conductor in comparison with the circuit board made of FR4 material and possessing 100 times the thermal conductivity, approximately 30 W/(K·m). On the ceramic board there are three gold-plated contact rings known as pads. The innermost circular pad conducts the signals sensed by the needles at temperatures reaching 300 °C as they probe the wafer from their ring, and sends the signals on to the two outer pad rings. There are sprung contact pins arranged on these two outer pads. 300 °C is the maximum temperature to which these spring pins are exposed (Fig. 3). The pins ensure that a connection is made between the ceramic board and the underside of the circuit board, right through the steel cooling chamber (Fig. 4). Thermal imaging and the use of temperature sensors has proven that the temperature of the circuit board rises to no more than 65 °C though the wafer temperature is 300 °C (Fig. 6).

Figure 4: Air flushing chamber (background) around measuring apparatus protecting the circuit board (foreground, bottom side with contact rings). Photograph: IMMS.



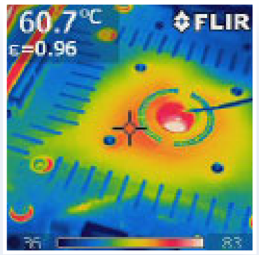


Figure 6: Thermal image of circuit board. Photograph: IMMS.

Conclusions and Outlook

By pursuing the approach described and by this means achieving characterisation of high-temperature ASICs it has been proved that complete semi-automatic testing of wafers at temperatures up to 300 °C is feasible. The ASICs thus processed possess the necessary functionality. They are to be subjected to long-term testing for the rest of the project period. The apparatus was designed in such a way as to be capable of use for planned re-designs and, in the wider field, of easy adaptation for other ASICs operating in this temperature range. The inexpensive standard FR4 circuit boards are adequate for alternative testing which needs to use active components. Besides this valuable feature, the layout of the ceramic board permits different probe rings to be inserted, with different needle positions.

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sMobiliTy

Field-tested energy-optimised wireless sensor solution for traffic applications

Installation of a wireless traffic sensor in Erfurt, Germany. Photograph: IMMS.

Objectives

IMMS has researched, designed and developed a wireless sensor network for a ”tactile road“ and has now also tested it in practice with the intention of progressing electric car mobility. Electric vehicles have a shorter range between refuelling episodes than the ordinary type but also take longer to refuel. Consequently, to enable them to be navigated optimally, at maximum range and minimum travelling time, up-to-date local information on such things as traffic flow is vital.

The IMMS system captures data on the number, type and speed of passing vehicles by means of magnetic field sensors installed in the road surface. The system works by passively registering local changes to the earth's magnetic field caused by the traffic. The vehicle type is classified and its speed determined from what is detected. In this IMMS-developed method, the data on type and speed of vehicle at a site is registered wirelessly, collected in a gateway near to grouped detectors and then sent to a data concentrator in the traffic control centre of the model town, Erfurt, in central Germany, where a new wireless network was installed in April 2015. With its 172 sensor nodes and 17 gateways, this is already improving on the previous standard of data capture.

Initial investigations

Many features of sensors installed into a road surface present a considerable challenge: they must be robust enough for outdoor conditions, have long-lasting but compact batteries, sustain widely fluctuating temperatures and serve reliably as wireless communicators. The system itself has, furthermore, to be flexible. It must accept the removal or relocation of sensors and/or the addition of further sensors. In anticipation of these challenges, IMMS investigated the radio communication conditions fully in advance, examining a variety of antennae and looking at the energy consumption of various system components in different scenarios. It also studied the applicability of energy harvesting, as explained in the annual report for 2014. From all this work, IMMS created a flexible system and was able to extend it with separate environmental sensors to facilitate emissions-dependent traffic control. After prototypes had been built and tested, the components were prepared for use in the Erfurt field-test.

The ”tactile road“ components for the field-test

Figure 1:

Sensor electronics and installation pod (diameter 7 cm, depth 12 cm). The traffic sensors are compact embedded systems using optimised boards and a battery, all contained in a plastic pod and easily installed in a drillhole in the road surface. Photograph: IMMS.

Traffic sensors

These compact embedded systems comprising a battery and electronics optimised by IMMS are installed with relative ease into a drillhole in the road surface (Figure 1). The main electronic components are a combined micro-controller and receiver (Atmel ATmega128RFA1), a magnetic field sensor and a planar antenna.

The signal from the sensor is sampled at 128 Hz. It is a measurement of changes to the earth's magnetic field occurring when a vehicle passes, with recognition of when the movement starts and finishes, and in combination with other captured data, a distinction between cars and lorries.

In standard operating mode, the data when detected goes directly to the assigned gateway which will ideally be in direct line of sight up to 75 metres away. For secure communication of this data, IMMS has implemented a procedure with cryptographic hashes as part of a tailor-made application protocol developed at IMMS (with IEEE 802.15.4 and TinyOS as basis) specifically for communicating across the network of sensors. It enables not only the passing of status messages and data but also the passing of commands from the gateway to the sensor, and ensures synchronous timing. Vehicle speed data is derived by correlating the measurements registered by paired detectors installed at a specified distance from each other in the direction of traffic flow. Depending on what is required in the particular instance, the sensors can be operated in a variety of data acquisition modes (events, aggregation, raw sensor data etc.) and their batteries will last up to two years.

Traffic gateways

The gateways developed by IMMS act as the indispensable, central component of a data capture location and thus of the whole traffic sensing network. These gateways transmit the data from their assigned sensors by wireless radio and HTTPS to the data concentrator for Erfurt. They also monitor the status and permit remote configuration of the sensor network.

IMMS has based its gateway development on its own flexible embedded Linux platform, BASe-Box, designed for tough industrial environments with a maximum power consumption of 1.7 Watts. The BASe-Box is a motherboard with an ARMv7 processor (Cortex A8) and sockets for extension boards. The basic motherboard has been turned into the gateway by IMMS by developing and adding the following extension boards:

- one board for both power supply (voltage range from 9 to 36 V) and communication (wireless radio, sensor network)
- a cascadable I/O board (with 16 potential-free contacts) providing (if four boards are used) up to 64 contacts in all
- boards to manage battery charging and monitoring

Three versions of the IMMS gateways have been developed. The first two are installed four metres above street level on traffic lights or lamp-posts.

- Standard version to fix on outdoor posts with permanent power supply (Figure 2)
- Battery-boosted variant to fix on outdoor lamp-posts with nocturnal electrical power
- Version for integration into the controls of a traffic light complex using potential-free contacts (installed in control cabinet)

Figure 2:

Standard version of gateway with permanent power supply. Photograph: IMMS.

Figure 3:
Environmental sensor exposed to show power supply, gateway electronics and sensor system (on boards from left to right).
Photograph: IMMS.

The Institute has used Linux, C++ and the Qt framework to create the software for the differently configured hardware, permitting appropriate configuration of the relevant functions. In addition, the dedicated application protocol in the sensor network allows the gateway to make use of compensation mechanisms relating to robustness and error tolerance if radio communication to sensors is temporarily interrupted, which is unavoidable in practice. These mechanisms will, for example, if the need arises, compensate for lost messages by using counters or extrapolate other necessary values.

The following data can be captured for traffic flow with the new hardware and software system: traffic density (vehicles per hour in total), breakdown into vehicle type and average speed (km per hour), occupation times (vehicle present above sensor in % of set interval period), and record of ground temperature in °C. The interval for the transmission of these details to the data concentrator can be freely configured; in the Erfurt field test, the interval is set at one minute, so that up-to-the-minute details are available for purposes of traffic situation analysis. Information on the status of the individual components is also transmitted, but at longer intervals.

Environmental sensors

To support emissions-related control of traffic, the environmental sensors analyse and record levels of nitrogen dioxide, carbon dioxide, carbon monoxide, temperature and relative humidity. All this data goes direct to the data concentrator. Upstream communications are very similar between traffic gateways and the gateway for the environmental sensors. Therefore, a gateway unit has been incorporated into the environmental sensor system of a local manufacturer, sharing the robust outdoor housing (Figure 3).

This choice of solution at IMMS has the potential to undercut the price of other commercially available air pollution sensor systems, which makes it attractive to local authorities subject to ever stricter regulations concerning finely-tuned immissions analysis. The fact that the system has been extended to include the environmental sensor clearly indicates that in future it will be possible to implement other or additional sensor systems on the platform.

Data concentrator

The application software for the Linux-based data concentrator has been developed by IMMS, and aggregates the data from all the gateways, i.e. the data from every traffic and environmental sensor in the urban area. This data is both stored and transferred, using the OCIT-C protocol, to Erfurt's main traffic computer, where it is processed by the overall traffic management system. The software also has a web frontend based on HTML5 and AJAX with which the system can be configured and the system status monitored (Figure 4).

Result of the field-test

In the period from April to September 2015, all components and techniques developed across the project as a whole were put through a field-test. Drivers of electric vehicles tested the new infrastructure in two demonstrators. One was the sMobiliTy City Erfurt demonstrator. Here a gateway is installed at 17 locations across the urban area of Erfurt, with 172 traffic sensors in all; there are also two environmental sensors. In the Erfurt traffic management centre, there is a data concentrator. 14 of the gateways are the standard version, two have battery buffering and one is an I/O version in a set of traffic lights. The new hard- and

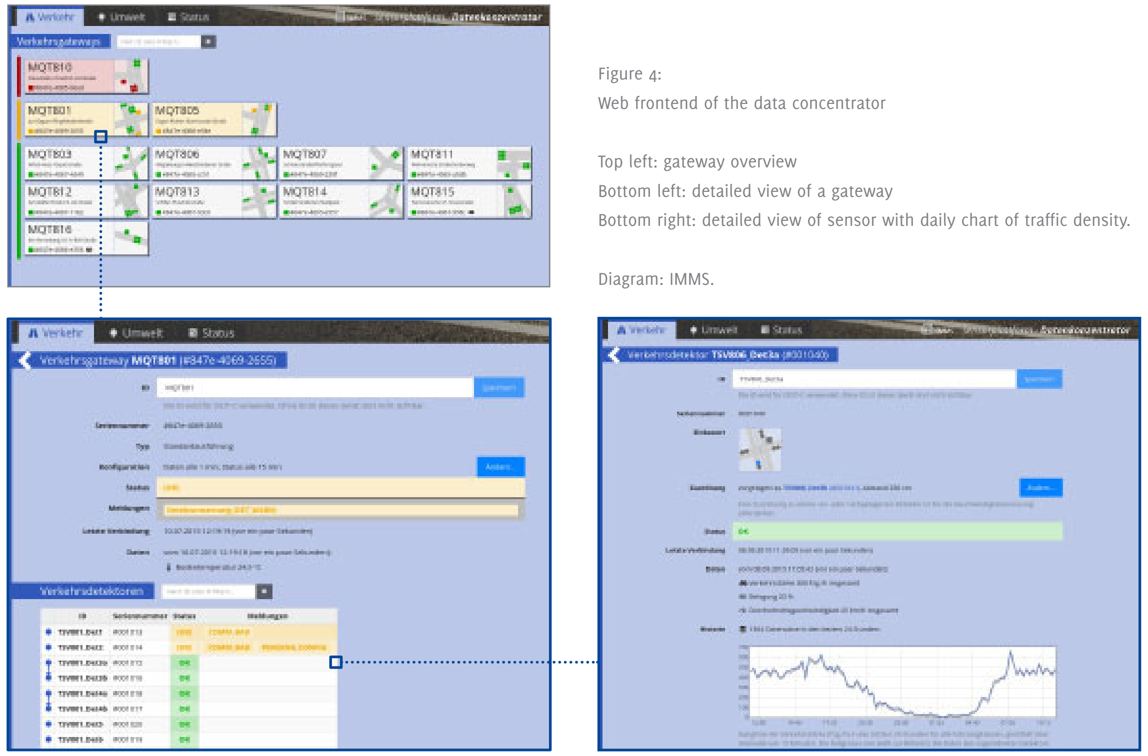

Figure 4:
Web frontend of the data concentrator

Top left: gateway overview
Bottom left: detailed view of a gateway
Bottom right: detailed view of sensor with daily chart of traffic density.

Diagram: IMMS.

software complements the pre-existing traffic monitoring system so that far more detail about traffic at the locations in question can be acquired. On the basis of all this detail, it will be possible to improve the accuracy of models and forecasts for traffic management purposes. Information is also being obtained on the nature of traffic flow after crossroads have been negotiated. The elements of the system are being left in place to allow their long-term stability and potential lifetime to be assessed.

The field-test has served as proof of functionality for the sensor platform. The choice of sensor sites has also enabled various potential disruptive influences to be investigated in practice. A selection of constellations with a potential impact on radio contact to the gateway has been analysed. Factors considered may be the stationary type such as buildings but also temporary ones such as changes in weather or variation in traffic conditions at different times of day. One result is that there can now be more precise recommendations on how to select sites for future installations. Another is that there is full confirmation of how necessary it was to integrate all the mechanisms mentioned so that the error tolerances will cope with temporary disruptions.

Future prospects

With sMobiliTy, IMMS has taken know-how built up in the Institute over many years on how to make smart sensor networks and has extended it to the traffic infrastructure, where yet more progress is planned. A number of ways of applying the principles are being pursued. One of these involves areas such as railways. The Institute is about to set up an easily accessible realistic test environment in front of the IMMS premises at the Ernst Abbe Zentrum in Ilmenau. Monitoring of parking spaces and a range of other potential improvements are to be explored. Examples are energy management using alternative hardware devices, better and more adaptive sensor signal evaluation, and the development of repeaters to extend the signal capture distances.

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SONOTEC

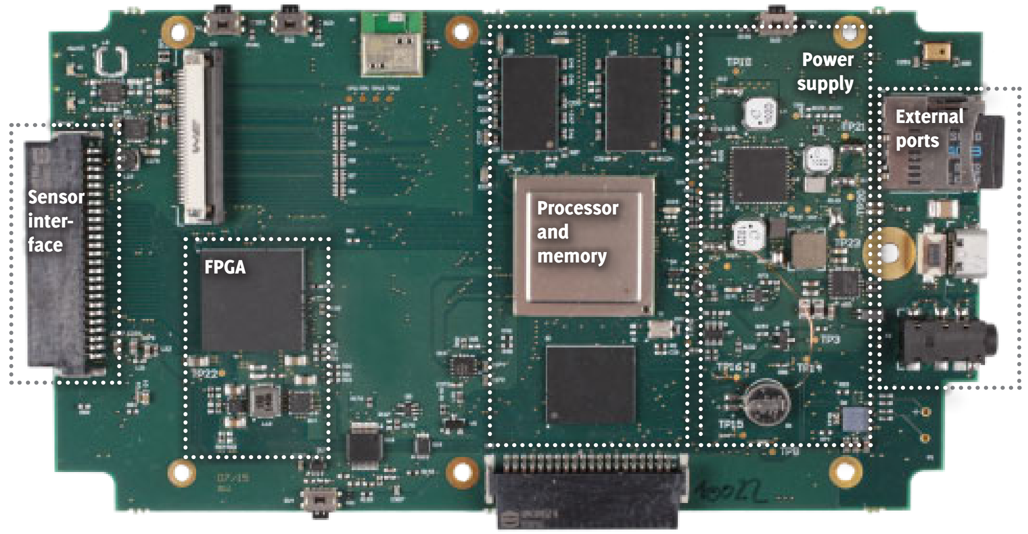
Finding leaks in industrial processes with ultrasound sensors – **a digital solution for the analogue world.**

Taking measurements on the hardware developed by IMMS for a hand-held digital scanner that will find and evaluate leaks in compressed air tubing by means of ultrasound. Photograph: IMMS.

Objectives

Up to 10% of all electrical energy used in industry goes solely into the production of compressed air. Approximately a third of this air leaks away, causing not only wasted energy and increased costs in these processes but also malfunctioning of the relevant machinery. As an approach to this problem, ultrasonic technology has already been employed for some time in the finding of leaks. The established analogue inspection methods are certainly robust, simple and reasonably priced. However, they only achieve detection of ultrasonic waves in a narrow frequency band with a width usually of about 4 kHz. This results on one hand in high sensitivity. On the other hand the significance of the data extracted from the signal may be limited, because narrow frequency range fields of the spectrum are arbitrarily selected which may not contain crucial audio events. In consequence, maintenance staff are often faced with the task of detecting compressed air escapes with very narrow-band analogue testing equipment and very rough estimated values. It is not uncommon for test measurements to have to be written down by hand. Any computation of the losses through leakage will barely be possible on the basis of this information, a fact which complicates any planning of effective measures when it comes to preventive maintenance and energy management. For the problem described, a completely new approach and new solutions are demanded by the new industrial revolution represented by Industry 4.0 and Maintenance 4.0. They require networked systems, mobility, instant availability and the evaluation of data for process optimisation purposes.

With this in mind, SONOTEC and IMMS have now developed an innovative, digital sonographic testing device. The hand-held tester with a five-inch touchscreen provides preventive maintenance by a first-time combination. It contains an innovative measuring system that covers a wide frequency range (from 20 to 100 kHz) and innovative sensors for both structure-borne and air-borne sound, combined with smart apps that are intuitive in use. It features storage of test data, levels and spectrograms, generation of test reports and camera documentation of leaks. To transmit data efficiently and to enable the data to be integrated into existing systems, the device uses interfaces like Bluetooth, USB and SD/MMC.



Circuit board developed at IMMS fur the new digital ultrasonic leak scanner. Photograph: IMMS.

SONOTEC was the developer of the overall system concept for the manual device, of the hardware and software for the ultrasonic detectors and of the application software including the data evaluation algorithms and user interface.

IMMS was the designer of the digital components of the hardware and the developer of the FPGA firmware which is crucial to the performance of the device. IMMS also adapted and ported the Android operating system and developed algorithms by means of which the ultrasonic audio signal is converted into audible output. This last feature enables staff to make the association they have been used to on analogue devices.

Overall concept

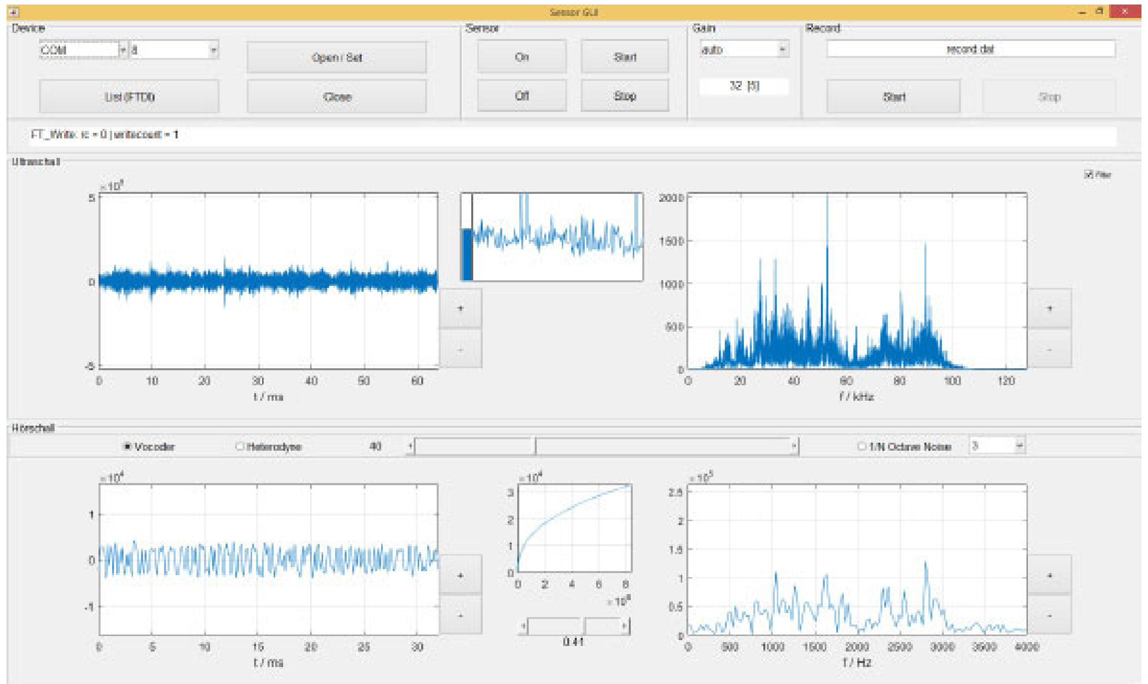
To enable the physical information contained in the ultrasonic signals to be utilised, broad-band detectors require high sampling rates and high-performance signal processing. SONOTEC has therefore carried out a thorough analysis of the physical fundamentals and the technical background both to leak detection and evaluation and to other applications, with complete re-evaluation. This has provided the basis for the new SONOTEC method which is used in this and other innovative applications, integrating powerful computation, flexible signal processing algorithms.

The result is a completely digital, scalable, modular solution. Two newly developed ultrasonics detectors are attached to the hand-held device by cable. These detectors do the signal pre-processing and analogue-digital conversion. The flexible digital interface between ultrasonic detectors and device leaves room for a wide range of possible future sensors. Further, the internal structure of the platform will also support extension to several fast measuring channels and some slower auxiliary data channels, a method which will mean this technology can in future be used in an ever-wider range of maintenance applications.

Operation of the device, internal computation and data communication are all managed by various apps which SONOTEC has developed. Encapsulated within the apps and the digital core processing unit are various complex functions. The fully-automated data throughput enables the user to concentrate on the inspection task and the various procedures involved in it. Of great importance for the ease of use is that the highly complex ultrasonic data employed are converted into easily understood graphics. High-performance chart and plot functions have been implemented to ensure that the results are simply and clearly represented. Features integrated into the device besides the measurement and signal evaluation functions themselves are maintenance notes and routing hints guiding the test engineer in complex setups.

The IMMS contribution

The know-how of IMMS in the field of digital architectures and of signal flows for acoustic measuring systems and audio pre-processing was fundamen-



MATLAB development environment to achieve audible output. Diagram: SONOTEC.

tal to the work. On the basis of the overall system concept, IMMS developed the hardware plans for the hand-held device, creating the circuit diagram and board layout to fit. IMMS integrated an FPGA for the implementation of the rapid-response signal processing algorithms. This hardware element, into which logic circuits can be programmed, is the crucial item influencing the level of performance. The IMMS contribution also included implementation of a NXP-iMx6 processor to evaluate the data and provide the human-to-machine interface. IMMS also carried out the integration of Bluetooth, two SD card slots and USB. The device memories are 1GB DDR3 and 8GB Flash. The lithium 15Wh battery can be charged via USB.

A parallel data bus enables the processor to access the FPGA memory and to transmit the computed data. It is also possible to use this interface to load the FPGA firmware into the FPGA.

FPGA firmware: signal processing and audibility

The FPGA can be easily reprogrammed, which means that application-specific algorithms can be implemented using additional firmware modules. The firmware developed by IMMS for the FPGA is used for the leak detection application of the device. The main elements of the firmware are the detector interface, the digital signal processing algorithms and the interface with the processor. At the interface to the detector, the serial data stream received is transmitted to the signal processing part of the firmware. It contains algorithms implementing signal correction filters, an FFT[1] (which enables frequency domains to be computed) and the conversion of the ultrasonic signal into the audible output.

For the device to be used easily, it is important how the ultrasonic signals are made "audible" to the testing engineer. In the old analogue method, the narrow frequency band surrounding the carrier wave frequency was just shifted into the audible range. The frequency spectra with a low sample ratio that used to be computed from this are, however, significantly different from spectra with higher sample ratios as used in the new method. In the new device it is effectively possible to employ all the state-of-the-art signal processing capabilities of acoustic measurement technology. IMMS addressed the audibility problem by developing an algorithm based on a voice encoder procedure which compresses the ultrasonic signals in the frequency range between 10 and 100 kHz by a factor of 32 and modulates them into the audible range. The algorithm was first implemented in MATLAB and then evaluated and optimised in cooperation with SONOTEC. After this, it was implemented in an FPGA, tested and verified.

1 **FFT** *Fast Fourier transform. An algorithm used to split up a digital signal into its frequency domains in order to enable the domains to be analysed.*


The newly developed ultrasonic detector in use for preventive maintenance purposes. The device was launched at the 2016 Hannover Messe. Photo copyright: fotolia: industrieblick/SONOTEC.

Operating system

For the complex hardware architecture of the device, IMMS started by analysing two possible operating systems, Embedded Linux and Google's Android. The choice fell on adapting Android to the requirements. The advantages of choosing this system for the new mobile leak testing device are the energy-saving functions that it includes and the fact that many users are already familiar with Android based devices and operation, which makes using the ultrasonic tester intuitive. As Android is available as open-source software, it is also easy to make any necessary adaptations or extensions. One example is that the user access to the internal memory and SD cards of the leak-finder was specially adapted from the standard method to fit it for use in an inspection device. Other advantages were also exploited, such as the high-performance Android Studio development environment which helped in the app creation. In addition, the Android application programming interface (API) makes it convenient to access a great number of standard functions for a manual device, such as creating the graphic user interfacet, accessing standard interfaces (like USB or audio ouput) and managing the standby behaviour.

For portaging of the operating system a board support package provided by the manufacturer of the CPU was used. IMMS made certain adaptations, particularly adapting some crucial components. Among these are most importantly the boot loader and Linux core, which have to support all of the hardware components of the device. The Institute developed a device driver which enables the ultrasonic data streams transmitted by the FPGA to be transferred to the host CPU of the device, where they are further processed. Here the particular challenge was to adapt the driver and FPGA to each other so as to achieve rapid and efficient data transmission at a rate of 3.8 MB/s. This speed means that data is transferred in real time, making available a continuous data stream, for instance for storage at an SD card or for output as an audible signal.

Future prospects

SONOTEC and IMMS cooperated closely on a pilot run and the testing of the devices manufactured. The leak-finder was presented to the public for the first time at the Hannover Messe in the spring of 2016, with great success. Currently, IMMS is supporting SONOTEC in its ongoing transfer of the small-scale manufacture to the device mass-production stage. This means that, before long, users will have in their hands a device which provides improved diagnosis of machinery faults so that less energy is wasted and, above all, more support is available for the assessment of trends and planning of maintenance intervals.

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RESEARCH SUBJECT
MEMS

Preparing vibrometry experiments on encapsulated MEMS structures. IMMS has been working in the IRIS project since 2015 on new measurement methods intended to enable quality testing of encapsulated MEMS during manufacture. Photograph: IMMS.

Highlights of 2015 in our MEMS research

Extending only over an area of a few square millimetres, MEMS (micro-electromechanical systems) combine micromechanical sensors and actuators with control electronics in a single device. The fields in which IMMS concentrates its R&D activities are MEMS-based electronic systems for innovative applications in industrial measurement technology, automation and control engineering and for special new growth areas such as the life sciences and biomedical technology. New approaches, such as the MEMS energy harvesting modules developed by IMMS, will make production of a wide range of innovative devices possible, with attractive market opportunities particularly for small and medium enterprises.

To open up these markets successfully in cooperation with its customers, IMMS has been continuously applying itself to extending its MEMS design capabilities. The Institute works in close cooperation with MEMS process development and manufacturing partners, itself focusing on the design of new mechatronic systems solutions. We put another main emphasis of our work on the characterisation and testing of MEMS components and modules by setting up specific laboratory equipment and by means of non-destructive measurement methods.

MEMS2015 project crowned by EDA Achievement Award 2015

On 21 May, 2015 at the edaWorkshop15 in Dresden, IMMS and University scientists from Ilmenau received the EDA Achievement Award 2015. This award is given by the edacentrum e.V. for particular achievement in R&D on electronic design automation, in this instance for work on circuit-based design of integrated MEMS-and-ASIC systems. MEMS (microelectronic circuits in combination with micromechanical structures) are a key to innovation in tool-making and machine-making and thus to the coming fourth industrial revolution, Industry 4.0. It is intended that SMEs who have little experience in design should be able to achieve new, tailor-made products by using a flexible MEMS and electronics system composed of building blocks. In 2015, the tried and trusted modular principle from microelectronic design was transferred by the researchers to mechanical systems and to MEMS. The two design methods (for the electronics and the mechanics) have been combined into a systematic start-to-finish procedure. As a result, a MEMS can now be simulated

Presentation of the EDA Achievement Award 2015 to Professor Ralf Sommer as head of the prize-winning research team. Photograph: Ralf Popp, edacentrum.

and verified as an entire system, which means that errors can be recognised and remedied early. Additionally, as part of the project, IMMS developed a readout circuit for a smart MEMS pressure sensor. The knowledge acquired was made use of in the new methodology. The readout circuit and the MEMS acceleration sensor with signal evaluation electronics which were designed using the new design tool were fabricated and then characterised at IMMS. These concrete results serve as the basis for the validation of the design methodology and for further work, for example in the RoMulus project.

Start of IRIS project

The IRIS project began in 2015. In it, IMMS is working on new analytic methods to permit quality testing of encapsulated MEMS during manufacture. MEMS structures, being so tiny and complex, are usually protected by a capsule from outside influences. However, these enclosed structures, which today have millions of applications, cannot as yet be monitored during production in the real encapsulation conditions. A MEMS manufacturer offering early recognition of any deviations during manufacture, followed by clarification and rapid correction, would have a vital competitive advantage.

The IRIS project therefore seeks to find new ways of analysing the encapsulated MEMS using innovative mid-infrared measuring technology integrated into in-line manufacturing controls as part of a photonic production supply chain. IMMS is developing measurement sequences to be fitted into the in-line process monitoring, so that the signals from several sensors at once can be registered. In addition, the Institute is researching new ways of triggering passive MEMS dynamically and developing the appropriate test structures. It is also validating the procedure and using the test structures which have been processed under manufacturing conditions to evaluate the measurement algorithms already devised.

MUSIK – merging microelectronics and micromechanics in design

IMMS investigated and modelled MEMS characteristics to develop basic blocks as the depicted BAW resonater for the design of complex functional groups. Photograph: IMMS.

Objectives

By 2020 it is expected that mobile data traffic will be six times that of 2015. The prediction is a rise internationally that reaches 24 exabytes – 24 times 1018 bytes – per month.[1] New radio bands with higher frequencies are already being prepared as one means of meeting the huge challenges. More bands with ever narrower distances between them will require more filters, both smaller and more powerful. In the tiny space available, these will have to ensure uninterrupted data transmission from the mobile communication devices. Not only these challenges but others presented by the move towards the Internet of Things require technology to take new routes. One is the idea of combining the strengths of microelectronics and micromechanics into the miniature machines known as MEMS (micro-electro-mechanical systems). IMMS has been working on such an approach. The products of the work are being tested and implemented in the MUSIK[2] research group of the DFG under the aegis of the IMN MacroNano® institute of Ilmenau University of Technology and the leadership of the RF and Microwave Research Laboratory.

1 *http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.html*
2 **MUSIK** *Multiphysikalische Synthese und Integration komplexer Hochfrequenz-Schaltungen, http://www.tu-ilmenau.de/musik*

Sensor and actuator components are typical of MEMS. These include pressure sensors, microphones, inertia sensors, cantilevers and scanning mirrors. There are also MEMS components for which the larger electronic counterpart is less than adequate in signal processing. The preferable MEMS components include bulk acoustic wave filters to assist in uninterrupted data transmission and MEMS switches which damp signals much less than do electronic switches. This latter feature is particularly useful at the high frequencies used in mobile radio communications.

New approach: models to permit simulation of entire systems

It is in the question of these filters that MUSIK is involving itself. The aim is to fuse microelectronics and micromechanics onto a single monolithic silicon chip, designing and simulating a multiphysical complex system then manufacturing it on a suitable substrate. This aim makes it necessary even at the design stage to replace groups of microelectronic functional elements with micromechanical ones or to complement one with the other if appropriate for the function. The designs must then be tested by whole-system

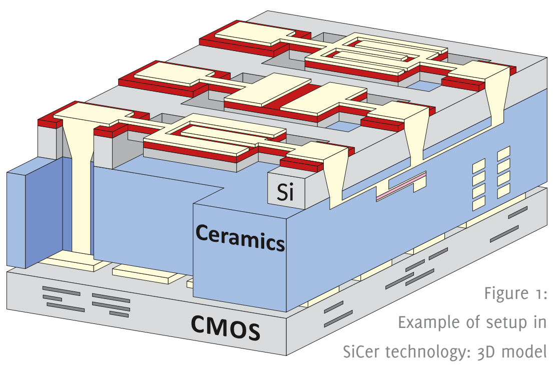


Figure 1: Example of setup in SiCer technology: 3D model of a MEMS-based multi-frequency oscillator on a SiCer substrate with hybrid integration. Source: TU Ilmenau / IMN MacroNano®.

simulation and optimised. IMMS has modelled these micromechanical functional groups so that they can be used for design and simulation.

The focus in MUSIK is on MEMS radio-frequency circuits. Here the work involves fully and consistently describing the electronic and mechanical properties and how they behave under the influence of heat and sound. The description is needed for everything from building block to system level. At the design stage the description starts at system level, top-down, with the system that is required to meet the particular system demands being broken down level by level into the individual components. Verification of the designs is carried out in the opposite direction, bottom-up. Approaching the development task across the layers in this manner permits characteristics of a communication system to be linked at a high level of abstraction with the physical properties of the building blocks and the appropriate manufacturing technology.

An innovative bonded silicon-and-ceramics (SiCer) substrate developed at the IMN MacroNano® of the TU in Ilmenau contributes its technology to the modelling, design and simulation. The SiCer permits new approaches to hybrid integration and helps avoid parasitic effects between wires (Fig. 1). The transceiver of an LTE[3] terminal is to serve as demonstration of the effectiveness of the multiple physics and multiple methodology.

3 LTE *Long Term Evolution, 4th generation mobile communication standard (3.9G)*

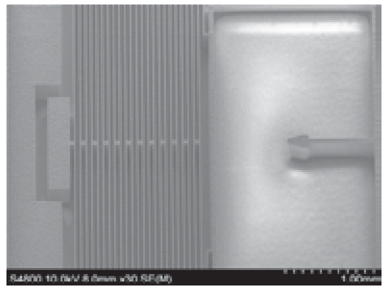


Figure 2:

Test structures of MEMS circuits.

Source: TU Ilmenau / IMMS.

A significant interim achievement is that IMMS has contributed Verilog A-based behavioural models for various types of resonators (Lamb wave type and BAW) together with the sort of MEMS circuit shown in Fig. 2 and is carrying out further work on these in collaboration with the project partners, work that is based on FEM modelling and very full study of the structures. These behavioural models constitute functional groups capable of parametrisation to be used in simulating and optimising the entire RF system. This process is carried out for the complete, unified MEMS design at a higher level of design which takes account of the advantages of the SiCer technology.

Example: Modelling of BAW resonators with the help of IMMS

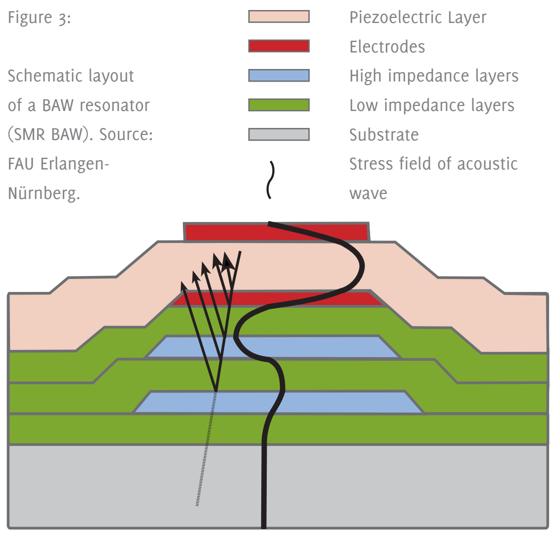
Figure 3 shows a schematic cross-section of an SMR BAW (solidly mounted BAW resonator). Mobile communications would be unthinkable today without such bandpass filters. An acoustic wave is produced within the piezoelectric layer by an alternating current audio signal at the electrodes. So that the acoustic wave does not spread into the substrate, a device known as an acoustic Bragg reflector made of layers of material with varying rigidity and density serves to reflect back the wave front. The thickness of the layers is selected to enable the reflective parts to vibrate with the same phase as the original wave, thus amplifying it. The result is a signal filter with strong signal supression above and below the limits of the frequency range and very little signal damping in the transmission range.

In mobile radio communication devices, these filters, which can be miniaturised to tiny sizes, will very precisely separate the radio bands used, resulting in uninterrupted data transmission. Nonetheless, despite this and their other advantages they will have to be very much improved. The data flood of the future will flow through frequency bands which are crowded ever closer together. The narrowing distances between these bands will cause the temperature-dependent shifts in the BAW filter frequencies to have an ever more critical effect. A typical shift of the filter edge of a typical BAW filter in band 30 can be up to 7 MHz because the ambient temperature can shift from -20 ° to 85 °C. This represents as much as 37% of the 19 MHz bandwidth in which a filter must switch from the pass operation to the cut-off operation.[4] In the

4 *P. Warder, D. Schnaufer, "Temperature-Compensated Filter Technologies Solve Crowded Spectrum Challenges", in IEEE Microwave Magazine, 57(11): 90–98, 2014*

Figure 3:

Schematic layout of a BAW resonator (SMR BAW). Source: FAU Erlangen-Nürnberg.



filter, besides these frequency changes due to the environmental conditions, there is also warming of the filter due to the signal current, which changes the behaviour of the filter. A further complication is the variability due to manufacturing processes. This may also reduce the effective band gap. These potential problems render indispensable the precise modelling of the temperature-related behaviour of the filters.

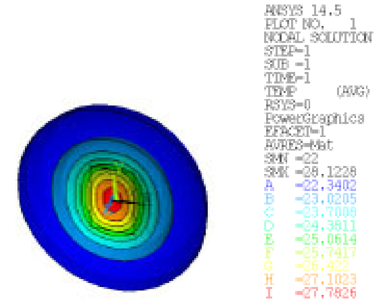
FEM simulation has been impracticable to date in view of the immense computation time required for all the acoustic, electromagnetic and thermal factors in a filter. However, a reduced FE model of the BAW structures has now been developed by IMMS and the University of Erlangen-Nürnberg and has made possible the efficient description of the layer temperatures relevant to accurate calculation of the filter frequencies. In addition, the reduced model takes account of the acoustic losses from the individual layers and of the electromagnetic losses in the electrodes and piezoelectric layer.

The problem is also being tackled in a different way from that shown in Fig. 3. Here, all the layers of material are modelled with infinite breadth and length because the area of the layers is so very much bigger than is their thickness. In comparative calculations this approach has proved appropriate and viable.

Behavioural models have been derived from the parametric FE versions and then implemented for simulation purposes using Verilog A as based on the Mason model for the electrical description of piezoelectric elements. By choosing a modular approach, it has been possible to produce models of BAW resonators with an arbitrary sequence of layers. Doing so has revealed that it is necessary to take account not only

Figure 4:

Temperature distribution in a BAW resonator as calculated using FE. Source: IMMS.



of the difference in temperature across the layers but also the difference within the individual layers so that the effects of the intrinsic warming on the behaviour of the BAW resonator can be accurately described (Fig. 4).

Future prospects

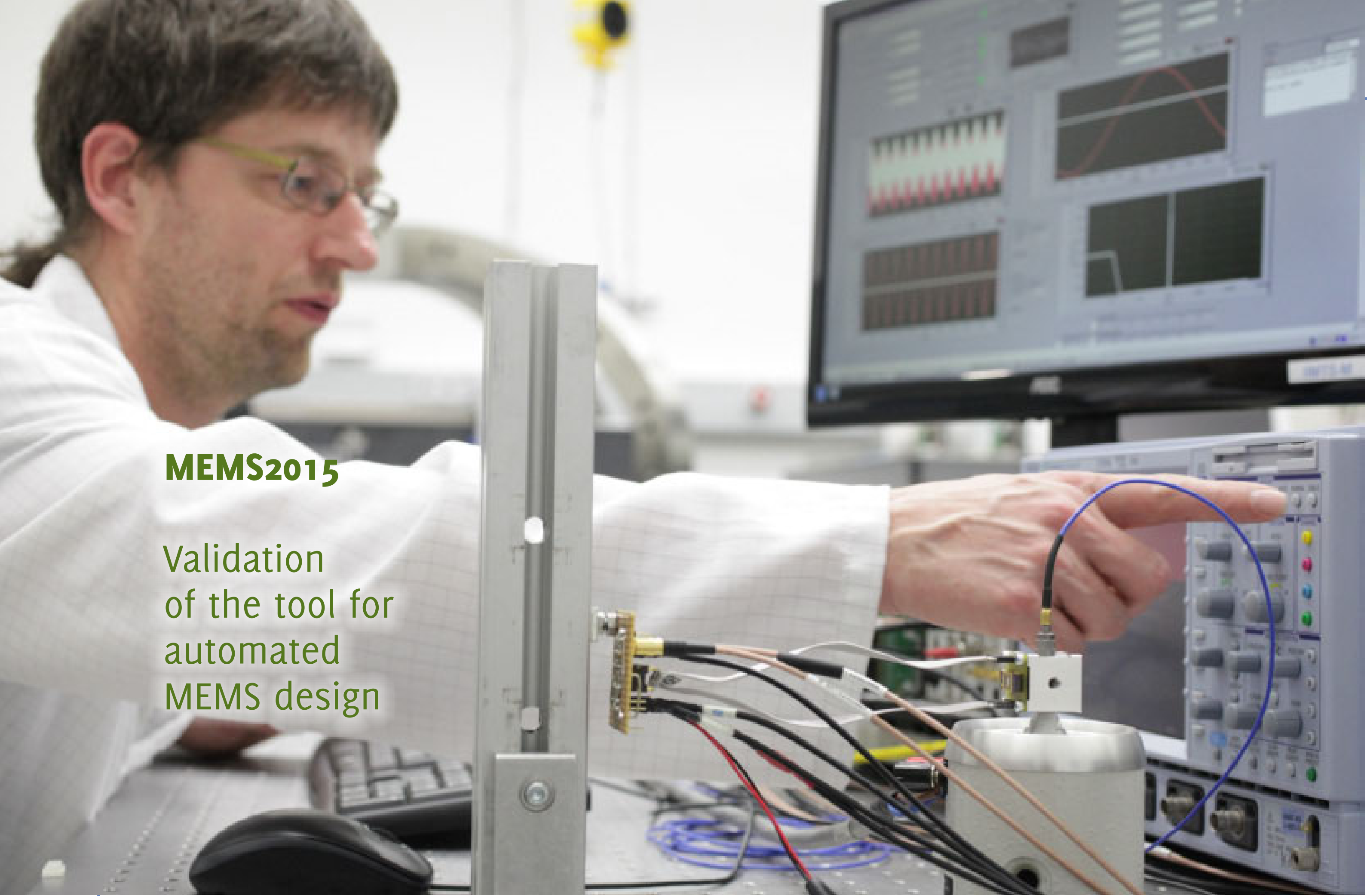
IMMS intends to do further work on shortening simulation time for the design of a BAW filter arrangement and to investigate the possible parasitic coupling of MEMS resonators due to the tight spacing involved in integration. The Institute also plans to extend the MEMS models which have been designed on the basis of SiCer technology to include thermal and non-linear effects and to use vibrometry to verify the test structures which have been created.

To the MUSIK project, IMMS has brought its long experience in the design, modelling and characterisation of MEMS. Together with the other partners, the Institute is reinforcing all this know-how together with the other partners in order to develop the novel circuit technology which will go by the name of "RF micromechatronics" and raise the focus of the present RF MEMS research from its present technological level with individual elements to the level of the full application-relevant system.

Contact:
Dr. Christoph Schäffel, christoph.schaeffel@imms.de

IMMS is a supported member of the FOR 1522 MUSIK research group and is funded by the DFG (German Research Council) within the sub-project 5 under the reference SCHA771/2-1.

Project partners are the Chair for Technical Electronics of the FAU Erlangen-Nürnberg and Ilmenau University of Technology with its Departments RF and Microwave Research Lab (HMT), Electronic Circuits and Systems (EES), Micromechanical Systems (MMS) and Electronics Technology (ET). Associated Industry partners are X-FAB Semiconductor Foundries AG, Cadence Design Systems Inc., Coventor SARL, Keysight Technologies Deutschland GmbH and TDK-EPCOS.



Preparing to take dynamic measurements at a shaker (foreground, r.) in validation of the acceleration sensor created using the design tool developed at IMMS. Photograph: IMMS.

MEMS2015

Validation of the tool for automated MEMS design

Objectives

Although in the field of microelectronics a highly automated, computer-aided procedure has been used for many years in designing integrated circuits, there has been to date no adequate methodology or design software for the design of silicon-based micromechanical components. MEMS (microelectro-mechanical systems) have had only a short history of mass production. 1994 saw Bosch launch the first mass-produced integrated pressure sensor onto the market. Software tools which help MEMS to be designed efficiently have been and generally available for less than ten years. On the whole, these tools have been the proprietary software packages belonging to the major players on the MEMS market: packages which contain vast internal know-how and are specially adapted to the specific manufacturing processes of the relevant concern. This software is directed at technological procedures but often lacks a hierarchical form of abstract design methodology, though such would be the key to enabling the development services industry to have a separate design process that does not involve outsourcing to fab labs, a separation which has long been established in microelectronics. The pressure on competing manufacturers has been heightened by the fact that market cycles for MEMS products from development to launch are getting shorter and shorter.[1] "Fabless" design will make the creation of useful MEMS products accessible even to small and medium-sized enterprises; however, this change will only come when software tools are freely available which open up a route to individual solutions for businesses collaborating on manufacture and development.

In the MEMS2015 project (which ended in 2015), IMMS tackled this problem with an approach that would combine and harmonise into a single whole the design of the mechanical and the electronic components of MEMS. Thanks to the novel composite design methodology which was developed, a MEMS can now be simulated and verified as a single unified system, so that errors can be recognised and remedied early. The design tool already presented in the IMMS Annual Report for 2014 is a vital element in our work on computer-aided design of electromechanical sensors. This is software which was first created for unidimensional acceleration sensors in XM-SC, the SOI technology of X-FAB AG. The tool works on the basis of an algorithm developed by IMMS to compute the various mechanical design possibilities likely to match the customer's requirements. The tool is, furthermore, a resource providing sensor models which can be integrated into established design tools. It will generate the necessary mask layouts for the manufacturing stage.

1 see the Emerging MEMS 2013 Report, Yole Développement, http://www.i-micronews.com/images/Reports/MEMS/Images_reports/Yole_MEMS_Devises_MEMS_benefits_from_shortened_development_times_August_2013.jpg

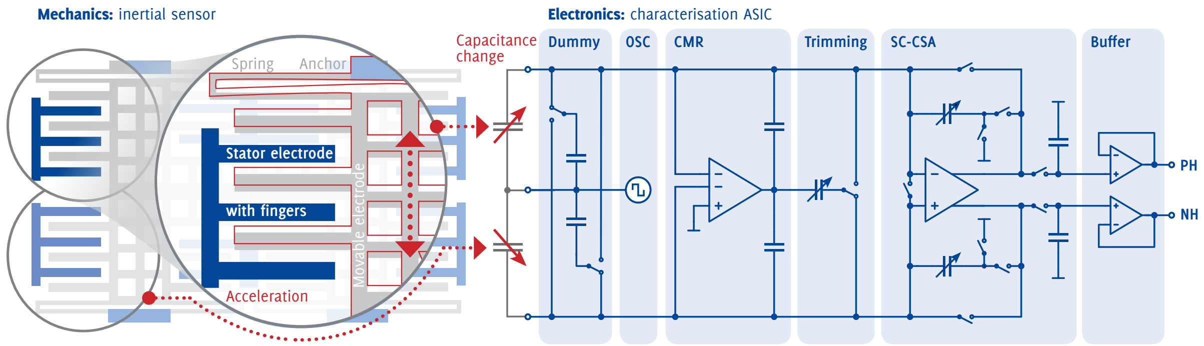


Fig. 1: Diagram and working principle of the acceleration sensor (l.) of which the capacitances are evaluated by the signal evaluation circuits (r.). Graphic: IMMS.

In validation of this new methodology and the new tool, IMMS has used the content of the new tool to design an accelerometer (acceleration sensor with high-precision signal evaluation) and then characterise it after fabrication.

Acceleration sensor

As its starting point for purposes of tool validation, the design took the following nominal sensor values: resolution of 0.1 %, capacitive difference of 70 fF at a maximum detectable acceleration amplitude of 10 g, basic capacitance of 2.5 pF. This last value is the capacitance between the electrodes when no acceleration is applied. All the values are in direct relationship to the sensitivity of the sensor.

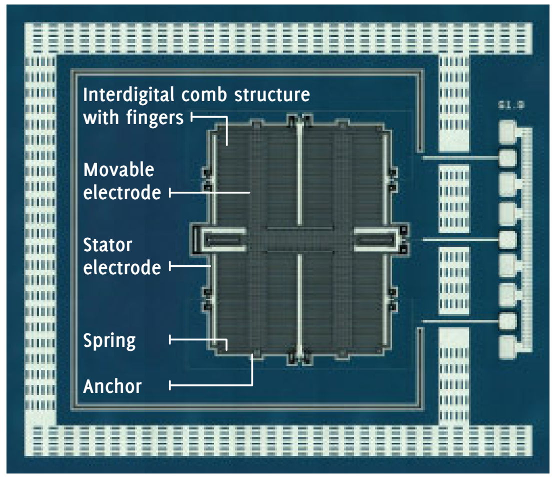
The result is a capacitive inertial sensor which detects acceleration in one spatial direction. On the sensor, the speed-up acting as stimulus shifts a movable electrode in relation to two fixed stator electrodes (cf. Figure 1, left), thus changing the capacitances which exist between the two. The change is read out in an electronic circuit which has been designed by IMMS (see Figure 1, right). In order to obtain the highest capacitance possible in a small space, the electrodes are laid out by the tool as interdigital comb structures: the fingers of a movable comb electrode engage with the fingers of the stator electrodes. For the sensor class here considered, the suspension of these structures is in the form of a type of spring known as a folded beam, where two beams lay parallel to each other.

The sensor properties are determined particularly by the number and length of the fingers of the comb and the width and length of the beams as calculated by the tool. These acceleration sensors are basically composed of a certain combination and number of primary modules. In their turn, the basic modules each contain the same functional units: a stator, which, in combination with a comb forms the fixed electrode, and a movable electrode, composed of a plate (which – depending on the technology – may have etching holes, comb structures with interlocking fingers and one or more springs, which are suspended on anchors (cf. Figure 1/2). The basic modules and functional units have been implemented by IMMS as a modular system in MATLAB software using object-oriented methodology.

ASIC for measurement of the acceleration

So that the acceleration measured by the sensor can be made available to a data processing system such as the system in a camera which senses orientation, the difference between the two capacitances of the sensor has to be measured. However, this difference is only a few femtofarads, and so small that to measure it is a huge technical challenge. The values for the finished accelerometer are up to approximately 70 fF. It is not possible to attach these sensors directly to commercially available measuring equipment: not even to the extremely high-precision equipment at IMMS. The reason is that the position of the necessary measurement cables cannot be kept fixed while modules under test are being exchanged and while the shaker is causing the motion which is inherent to measurements. Changing the position of the measurement cables already alters the capacitance by an amount greater than the change in sensor capacitance requiring detection.

Because of this, IMMS has developed an application-specific integrated circuit (ASIC) which is placed directly alongside the sensor and carries out the measurement there with high precision. The ASIC generates a robust output voltage which follows the difference in capacitance between the two sensors



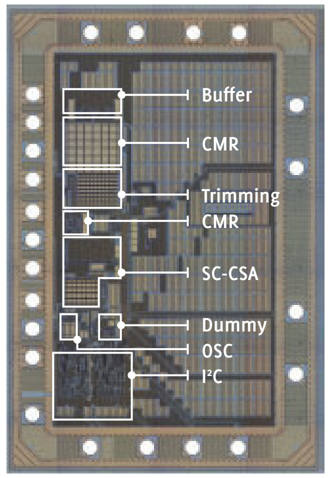


Fig. 2:

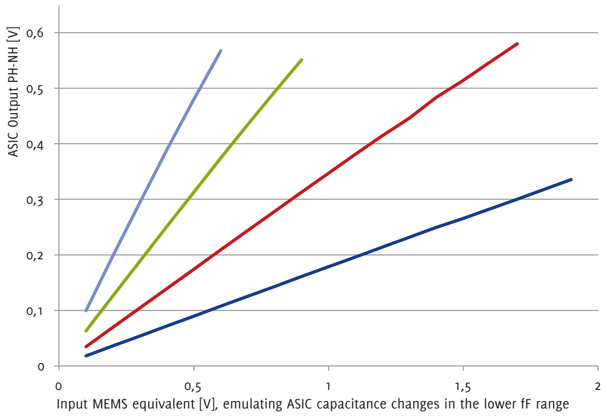
Complete acceleration sensor (l.) and evaluation ASIC (r.) with the relevant functional units.

Photographs and diagram: IMMS.

and can be transmitted without difficulty via long cables before being further processed in the next stage.

The central signal conversion takes place using a charge-sensitive amplifier (CSA) implemented as a switch capacitor circuit (SC circuit), a common mode regulator (CMR) and an oscillator (OSC). These are shown in Figure 1/2. The oscillator reloads the sensor capacitances periodically at a frequency of up to 1 MHz. The charge required for this is made available by the CSA. When the sensor capacitances distinguished by the motion are reloaded, a voltage difference arises at the output of this amplifier. This difference, which reflects the acceleration, is amplified by means of the buffer for transmission via cable. The CMR ensures that the circuit works in the correct position. The ASIC is configured via an I²C-interface. As a result, for example, the amplification can be set between 1.25 mV/fF and 10 mV/fF or two internal dummy capacitances can be activated to enable testing of the ASIC even without acceleration sensors. The

Fig. 3: The replacement inertial sensor circuit was used to demonstrate the signal transmission behaviour of the ASIC at various amplifications: the output signal from the ASIC is, as expected, in linear dependence on the alteration in capacitance. The four lines show the relationship for four amplification factors which can be set in the ASIC. Diagram: IMMS.



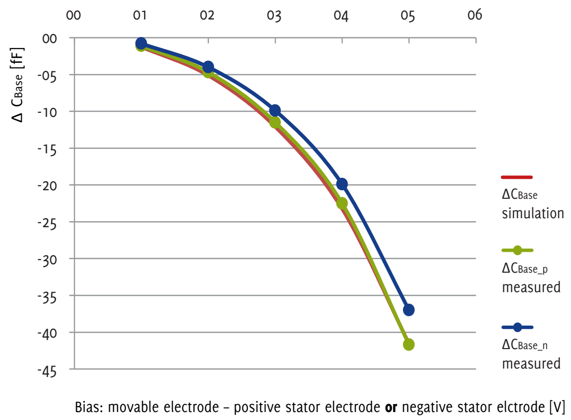
adjustable trimming capacitance allows setting of the zero point of the circuit. By this means, undesired differences in sensor capacitance can be compensated for using manufacturer's tolerances of up to 1000 fF at an accuracy of 0.5 fF. The ASIC has been characterised in the IMMS MEMS T-Lab.[2] It has been found to fulfil the detailed requirements of signal evaluation for the accelerometer.

Characterisation of the accelerometer

A number of test setups were developed to enable the design tool to be validated. In these setups, the processed acceleration sensors and signal evaluation ASICs were characterised both individually and in combination when constructed as a full sensor module.

A modular test platform was used to investigate the **ASIC**. This was configured in such a way that it was possible to carry out partially automated characterisation of the digital and analogue components of the ASIC and of their interplay. The inputs were, on the

Fig. 4: Alteration in basic capacitance (CBasis) by electrostatic deflection of the electrode using biasing. Diagram: IMMS.



2 *See the IMMS Annual Report of 2013.*

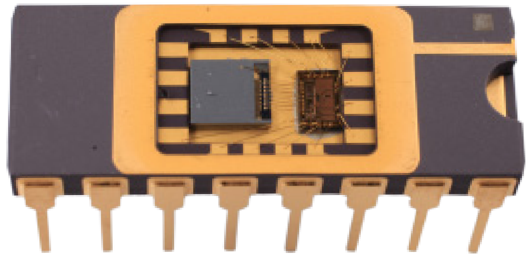


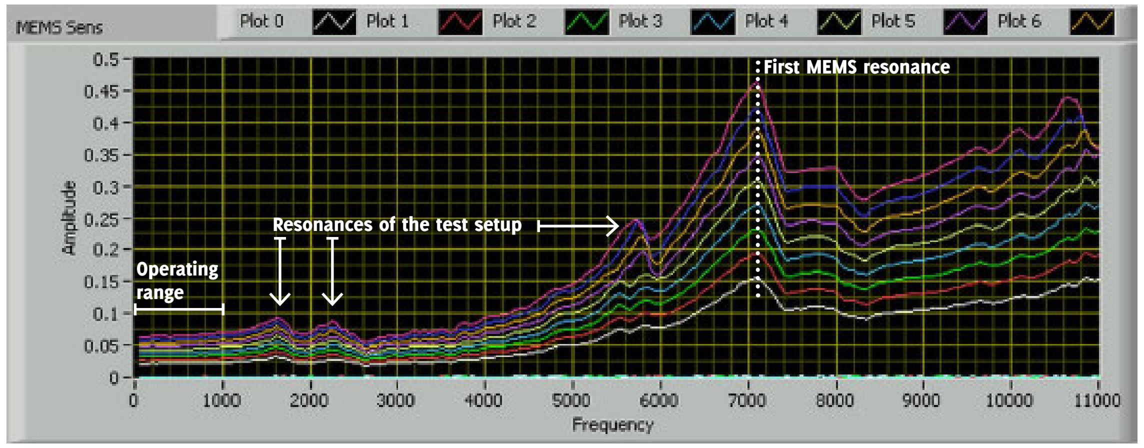
Fig. 5: One of the modules with encapsulated acceleration sensor (l.) and signal evaluation ASIC (r.) set up for the investigations on the shaker. Photograph: IMMS.

one hand, the dummy capacitances implemented in the ASIC and, on the other, a specially developed replacement inertial sensor circuit, which uses an electrical alternating voltage to imitate the changing capacity triggered in the accelerometer by changes in acceleration. As expected, the output signal from the ASIC is in linear relationship to the change in capacitance (cf. Figure 3) and independent of frequency in the relevant operational range.

An LCR[3] meter was first used to determine the basic capacitances at the **acceleration sensors** and the parasitic capacitances caused by the internal construction of the component at the wafer level. The testing card made specifically for the purpose was provided with particular guard technologies allowing individual capacitances to be determined independently of each other. As it is not possible to create acceleration while the module is being characterised at the wafer level, targeted biasing was used to deflect the mobile electrode electrostatically so as to achieve an appropriate alteration in capacitance. Conclusive measurements were thus made both of the simulated capacitance values and of their alteration on deflection (Figure 4).

To validate the **interplay between the two components**, modules were constructed (see Figure 5) and

Fig. 6: The graphs produced by a module on the shaker show the relationship between output voltage and frequency. Diagram: IMMS.



3 **LCR** *test unit for the measurement of inductivity, capacity and resistance.*

mounted on a shaker. It is possible by this means to characterise the complete system across a wide frequency range from 30 Hz to 13 kHz with acceleration of up to 10 g. As a result, the sensitivity of the module as constructed can be determined at various points of operation. Confirmation took place in this way for the resonance frequency of the MEMS structures as calculated in the simulation (Figure 6). It was also possible to establish that not only the micromechanics but also whichever construction and bonding technology is used can strongly influence the functioning of the system as a whole (see Figure 6). These observations will be incorporated into the future development of such test setups.

Future prospects

Further developments can take place on the foundation laid by the characterisation of the accelerometer, of the signal evaluation electronics and of their combined behaviour as a single system. For instance, in the context of the RoMulus project which began in 2015, the design tool (originally for a unidimensional sensor) is being extended to 2- and 3-dimensional sensors. Another example is the use of the ASIC as the basis of measurements taken on the type of sensor that is to be created in RoMulus using the extended tool. It is also hoped that the tool can be used in future collaborative projects with industry.

Contact person:
Dipl.-Ing. Roman Paris, roman.paris@imms.de

SPONSORED BY THE

Federal Ministry of Education and Research

The MEMS2015 project was funded by the BMBF (German Ministry of Education and Research) in its IKT 2020 programme, with the reference 16M3093. Partners of IMMS in the project were Bosch, Cadence, Carl Zeiss SMT, Coventor, Munich TU, TETRA, Bremen University and X-FAB.

Highlights 2015 in our research on Integrated Sensor Systems for Biological Analysis and Medical Technology

Increasing life expectancy in our societies lead to a rise of serious diseases such as cancer, cardiovascular disorders and dementia and to a growth of related expenditures for diagnostic analysis and therapy. Our research on microelectronic biosensor systems for medical diagnostics and personalised medicine contributes to reduce health service costs and to improve patients' quality of life.

IMMS applies a variety of sensor principles to the simultaneous detection of different biological and chemical measurands with the help of one integrated electronic device so that diagnosis is more conclusive and less prone to error. The work is based on familiar (and thus relatively inexpensive) standard semiconductor manufacturing processes which are adapted to new approaches and specific applications by means of particular functionalisation of surfaces and the use of biocompatible material. Our solutions should pave the way to conduct fast, reliable, cost-efficient and automated point of care tests, such as cancer screenings.

Start of ADMONT project

In the ADMONT (Advanced Distribution Pilot Line for More-than-Moore Technologies) project, the plan is to extend CMOS process technologies. Among other things, new sensors and MEMS components will be added, together with means of integrating OLED and 3D so that new applications will bring new stimulus to the fields of mobility, energy, health and manufacturing. The ADMONT consortium of nine partners will build up a "one-stop shop" in the form of a distributed More-than-Moore (MtM) pilot line. This processing line is to prove that the new concepts can be converted into products using the newly modified technology.

The IMMS role will be to validate these new semiconductor process technologies, building on the knowledge it has gained in the GreenSense research group. It will also contribute new "smart health" approaches to the ADMONT project. Among the foci will be modelling of energy autonomous sensor components for biological analysis, the development of wireless multi-parameter biosensor networks, the creation of a technology and IP platform and the construction of microelectronic prototypes for in vitro diagnosis of breast cancer.

Start of MIMOSE project

This acronym stands for a Monolithically Integrated Microelectronic in vitro Sensor Platform to be used in methylated cancer marking diagnostics. The project started in June 2015. IMMS is developing a prototype system for the field of early cancer recognition so that laboratory staff can come rapidly and reliably to the right diagnosis at the point of care. The project is focussing on the example of early diagnosis of cervical cancer. New principles of detection are being put into practice with electronic sensors that are capable of innovatory, exact, high-resolution recognition of DNA methylation markers. The automated diagnostic platform uses a dual microelectronic recognition scheme to detect the methylation markers which have been validated. The result will be high-quality, highly reliable cancer detection.

IMMS joins the PPA network in the Life Science section

Since 2015, IMMS has been involved not only generally in the Berlin-Brandenburg diagnostics network, BB DiagnostikNet, but also specifically in the PPA subnetwork working on Product and Process Security through Spectroscopic Analysis, where it is advancing analysis in life sciences. The direct goal of the PPA network is to bring highly sensitive, compact, modular, reasonably priced spectrometry devices from the drawing board to the marketing stage. PPA is focusing on three areas, life sciences, gas detection and hazardous substance detection. IMMS is involved above all in the life sciences work, offering the partners its insights and developments on application-specific integrated circuits (ASICs) plus a range of electronic sensor components applicable to the interface between microelectronics and the life sciences. IMMS seeks out suitable partners to benefit from the various applications and the multiphysical effects offered by the ASICs and sensors to biotechnology, chemistry and medicine.

Voices from Academia and Industry

Prof. Dr.-Ing. habil.
Peter Husar,

Head of Biosignal Processing Group at University of Technology Ilmenau. Photograph: Foto Müller, Ilmenau.

Khalid Ishaque

Chief Executive Officer, Pixium Vision.
Photograph: Pixium Vision.

Prof. Dr. Peter Husar, TU Ilmenau

"We had an ambitious aim when we were involved with our many partners throughout Europe in the EU 3DNeuroN project: it was to help people whose cellular tissue in the central nervous system (CNS) had been damaged by disease or wounds. Our idea was to target some control into the healing of the nerve-cell tissue, using a novel system which would be able to detect and stimulate neural activity in three dimensions.

We have developed such a system. Being capacitively coupled, it is electrically and biologically compatible with the human cell. It is a multi-sensor-actuator array, containing 800 sensors in all, with a three-dimensional structure allowing nerve cells to grow in an almost natural environment.

To enable the signals from all 800 sensors to be received simultaneously without interruption and also to enable the signals to be amplified with very little noise and evaluated, we needed analogue-digital ASICs. The ASICs had to operate on the tiniest of power inputs or there would be too much heat generated, damaging the nerve cells irreversibly. The challenge, which was immense and hitherto unknown in any such context, was met by the IMMS staff with their ASIC development skills. The results leave us feeling great satisfaction, for the vital step in development has meant that we have been able to provide our Finnish partners at Tampere University and our Swiss partners at Zurich ETH with a usable system. Applying the system in their initial experiments, they have already been able partially to achieve their neurophysiological aims by means of the necessary electrical stimulation.

The IMMS staff went about their work with us on the many challenges and vicissitudes of the project in a cooperative and constructive way, proving their high competence, flexibility, creativity and efficiency. We are already planning further projects and shall be delighted if we can continue this excellent collaboration."

www.tu-ilmenau.de/bmti/fachgebiete/biosignalverarbeitung/

Khalid Ishaque, Pixium Vision

"One must remember the notion that restoring some vision to those who have lost their sight is possible, has long been thought to be fanciful. However, we are in the New Age at the frontier of neuroscience, interfacing the worlds of the eye and the brain – "from the Photons to the Neurons". Such is the breadth and depth of the understanding required to build a world of bionic vision for those who have lost their sight. That is the mission of Pixium Vision.

The company is developing in parallel 2 innovative Bionic Vision Systems, which incorporate active implantable prostheses intended to treat and compensate for blindness resulting from the degeneration of retinal photoreceptor cells. These devices are intended for blind people with a functional optic nerve to enable them to regain greater autonomy and improved quality of daily living.

The Company harnesses the rapid advances in neuroscience, neuromorphic visual processing, microelectronics/nanoelectronics, optoelectronics, neurobiology and intelligent software algorithms.

IMMS delivered a vital contribution to our goal of restoring the sight of visually impaired people. The IMMS developed an application specific integrated circuit (ASIC) used in our intraocular implant that translates the incoming optical information into an electrical data stream which in turn is transferred to the optical nerve through a stimulator interface. The ASIC made by IMMS is the fundamental gateway between the real world and the optical nerve of the patient. This ASIC uses a photodiode for signal detection and a control circuit that distinguishes between parasitic or system relevant signals and activates an output driver in case of useful data. The IMMS furthermore developed an energy supply for the ASIC which we are using in our most recent systems as well.

We highly appreciate the cooperation with the IMMS that ran in an active and close information exchange with its competent technical experts. The IMMS remains a strong electronics partner of us for further prototypes in research and development."

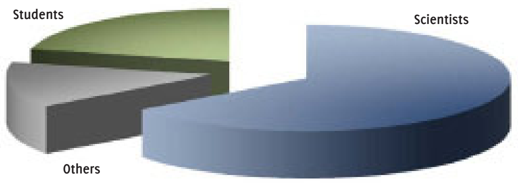
www.pixium-vision.com

PROOF THROUGH FACTS AND FIGURES

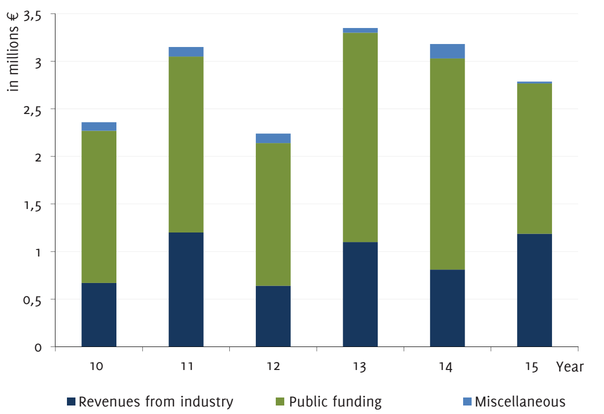
Preparing to take measurements at the wafer level in the class 7, DIN EN ISO 14644-1 cleanroom measuring lab at the Erfurt section of the Institute. Photograph: IMMS.

Facts and Figures

Staff



Project income



2015 saw 80 members of staff working at IMMS. There were 52 employed as scientists and 17 (FTE) students, i. e. 86% of the entire staff, who were directly involved in research and development.

The FTE figure actually represents 40 students availing themselves of the opportunities at IMMS to pursue research of relevance to real life. 11 of them came on internships. 18 have part-time student jobs. Six BSc and five MSc dissertations were supervised at the Institute. There are six IMMS researchers currently pursuing doctoral studies at various universities.

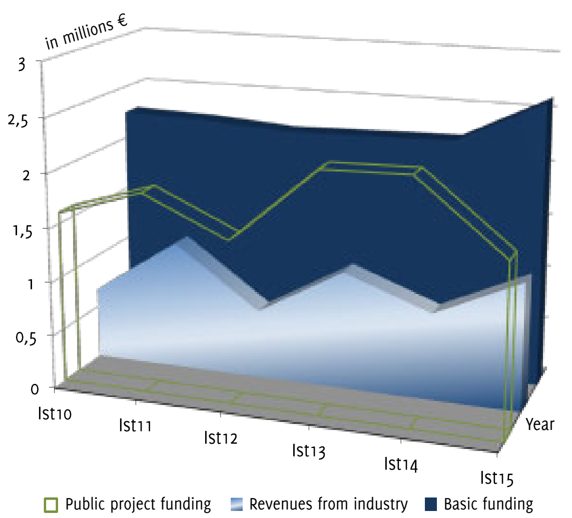
IMMS makes a point of engaging in undergraduate teaching in order to be able to attract enough of the highest quality graduates.

The proceeds from industrial research commissions increased by 27% compared with the previous year while income from publicly funded projects dropped by 13%. The profit share amounted to 60%. The actual income tends to reflect this relationship. Delayed payment of project funding that had been claimed occasioned a 30% reduction in income as against the previous year.

From both sources, IMMS is expecting a considerable growth in income for the years 2016 to 2018, having positioned itself strategically to meet the current requirements of industry and society. It is largely with industry that the projects are taking place, a fact which endorses the respect in which IMMS is held as a research partner. The Institute has succeeded in achieving increased project activity by getting involved in research networks. The aim is to convert the good research results as quickly as possible into industrial applications. This will benefit SMEs most of all. The conversion process can be stabilised if the SMEs are combined into regional, product-oriented value-added supply chains. Access to innovation-driven markets is coming more and more to require systems competence in the design and manufacture of products, using micro- and nano-technologies. IMMS is excellently placed in this respect.

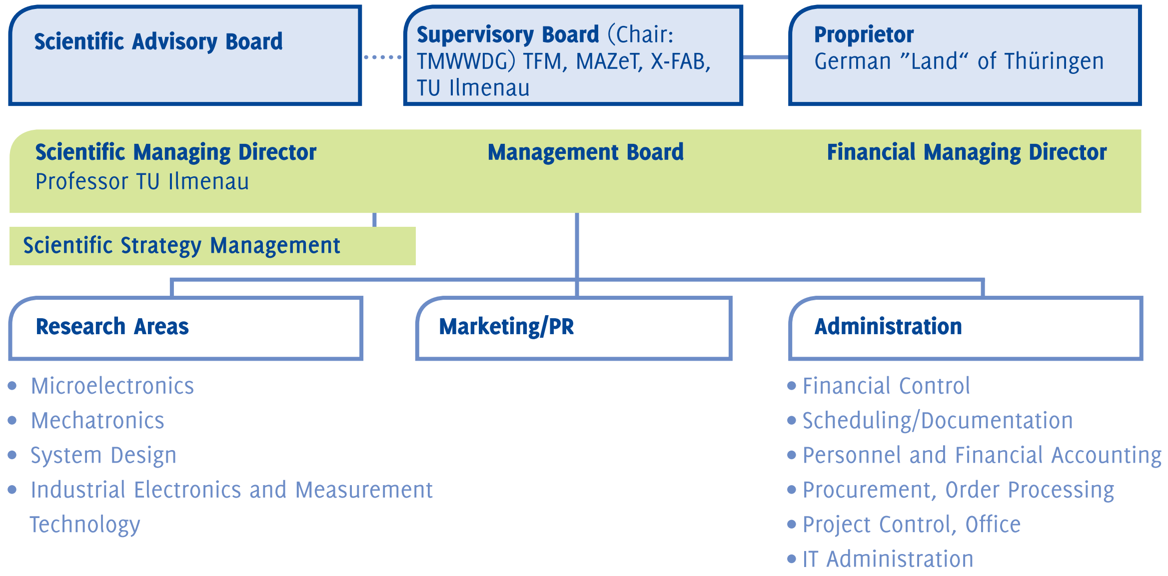
Thüringen as federal "Land" maintained its level of support in 2015, adapting the institutional instruments to the current academic environment. The work IMMS could do in conjunction with regional SMEs has particularly benefited.

Pillars of financial support



* **FTE** *Full time equivalent*

Organisation



Scientific Advisory Board

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- **Assistant Chairman:** Olaf Mollenhauer, Managing Director TETRA GmbH, Ilmenau
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- Dr. Fred Grunert, Technical Director MAZeT GmbH, Jena
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- Dr. Peter Schneider, Managing Director, IIS Fraunhofer Institute for Integrated Circuits, EAS Design Automation Branch Lab, Dresden
- Prof. Dr. Ansgar Trächtler, Chair of Control Engineering and Mechatronics, Heinz Nixdorf Institute, University of Paderborn
- Prof. Dr. rer. nat. habil. Andreas Tünnermann, Scientific Director, Institute of Applied Physics, Friedrich Schiller University, Jena

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- **Chairman:** Robert Fetter, Ministry for Economic Affairs, Science and Digital Society, Thüringen *(since 25.03.2015)*;
  Dr. Jörg Prinzhausen, Ministry for Economic Affairs, Science and Digital Society, Thüringen *(until 24.03.2015)*
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- Dr. sc. Wolfgang Hecker, Director, MAZeT GmbH, Jena
- Herr Ulrich Kamper, Ministry of Finance, Thüringen *(since 01.04.2015)*
- Dr. Jens Kosch, Chief Technical Officer, X-FAB-Semiconductor Foundries AG Erfurt
- Thomas Weißenborn, Ministry of Finance, Thüringen *(until 31.03.2015)*

Lectures, lecture series

Prof. Dr. Ralf Sommer at Ilmenau University of Technology, Department Electronic Circuits and Systems:

- „Grundlagen der analogen Schaltungstechnik“, lecture and tutorial, bachelor students 3rd semester,
- „Rechnergestützte Schaltungssimulation und deren Algorithmen (EDA)“, lecture and tutorial, bachelor and master students
- „Modellierung und Simulation analoger Systeme“, lecture and tutorial, bachelor students

Prof. Dr. Hannes Töpfer at Ilmenau University of Technology, Department of Advanced Electromagnetics:

- „Theoretische Elektrotechnik I und II“, lecture and tutorial, bachelor students 4th/5th semester
- „Grundlagen der Modellierung und Simulation“, lecture and tutorial, bachelor students 5th/6th semester
- „Schaltungen der Quanteninformationsverarbeitung“, lecture, master students 2nd semester
- „Elektromagnetische Sensorik“, lecture, master students 2nd semester
- „Technische Elektrodynamik“, lecture, master students 2nd semester
- „Supraleitung in der Informationstechnik“, lecture, master students 1st semester
- „Projektseminar ATET“, seminar, master students 1st semester

Dipl.-Ing. Sven Engelhardt for the ”Berufsakademie Eisenach“ (University of Co-operative Education)
„Mikrocontrollertechnik“, tutorial, bachelor students 5th semester Mechatronics,

Events

Trade Fairs

embedded world 2015 Major embedded object event for all manufacturers, developers and providers of hardware, software, design tools and services in the value chain of embedded system technology. Nürnberg, February 2015 *(IMMS was co-exhibitor on a stand shared with OSADL)*

Biotechnica International trade fair for Biotechnology, Life Sciences and Lab Technology, Hannover, October 2015 *(IMMS had a presentation on the PATON stand: Research for the Future)*

iENA International trade fair on Ideas, Inventions, New Products, Nürnberg, November 2015 *(IMMS had a presentation on the PATON stand; IMMS won silver medal)*

MEDICA International trade fair for medicine, Düsseldorf, November 2015 *(IMMS was co-exhibitor on a stand shared with DiagnostikNet-BB)*

Workshops / IMMS as Host

Sensor networks seminar Embedded Systems – en Route to the Smart Sensor, given at Stuttgart in February 2015 *(event organiser: AMA, German Association for Sensors and Measurement; scientific direction: IMMS)*

Alumni symposium ”Engineering and Computer Science – Application of Computers“, March/April 2015 *(event organiser: TU Ilmenau, guided tours and lectures at IMMS)*

Embedded Linux workshop Opportunities, Practical Possibilities and Legal Aspects of Open Source, workshop jointly organised with OSADL eG, Ilmenau, November 2015 *(IMMS acted as host, organiser and presenter)*

Lange Nacht der Wissenschaften (The Long Night of the Sciences), November 2015, IMMS Erfurt *(demonstrations, lectures)*

Publications 2015

Conferences with contributions by IMMS – an overview

TuZ 2015 27th GI/GMM/ITG workshop on testing methods and reliability for circuits and systems, Bad Urach, Germany, March 2015 *(2 lectures/poster presentations)*

DATE 2015 Design, Automation & Test in Europe, March 2015, Grenoble, France *(poster presentation)*

GeMiC 2015 German Microwave Conference 2015, March 2015, Nürnberg, Germany, *(2 lectures/papers)*

edaWorkshop 15 May 2015, Dresden, Germany, *(lecture/paper, EDA Achievement Award)*

DAC 2015 Design Automation Conference, June 2015, San Francisco, USA *(invited talk and contribution to a panel discussion)*

Thüringer Maschinenbautag June 2015, Erfurt, Germany *(lecture)*

SPITSE 2015 2nd International Scientific Symposium ”Sense. Enable. SPITSE. 2015“, June 2015, St. Petersburg, Russia *(3 lectures including one keynote)*

PES 2015 12th International Conference on Applied Electromagnetics, August 2015, Niš, Serbia *(lecture/paper)*

ESSCIRC 2015 41st European Solid-State Circuits Conference, September 2015, Graz, Austria *(lecture/paper)*

FDL 2015 Forum on specification & Design Languages, September 2015, Barcelona, Spain *(2 lectures/papers, Best Paper Award)*

DASIP 2015 Conference on Design & Architectures for Signal & Image Processing, September 2015, Kraków, Poland *(paper and demonstration, Best Demo Night Award)*

DFAM-Symposium ”Current and Future Developments in Microelectronics and Automation“, Frankfurt am Main, September 2015 *(moderator, programme advisory board)*

RFI-Workshop Workshop on RFI Threats to GNSS, September 2015, Aachen/Aldenhoven *(live demo)*

TELFOR 2015 23rd Telecommunications Forum, November 2015, Belgrad/Serbien *(lecture/paper)*

Reviewed Publications

Wireless solution for traffic monitoring, Elena Chervakova[1]. Marco Götze[1]. Tino Hutschenreuther[1]. Hannes Toepfer[1,2]. Bojana Nikolić[3]. Bojan Dimitrijević[3]. *12th International Conference on Applied Electromagnetics, August 31 – September 02, 2015, Niš, Serbia,* Elektrotechnica & Elektronica E+E Vol. 50. No 9 – 10/2015, Pages 2 – 6, ISSN 0861-4717. [1]IMMS Institut für Mikroelekronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, [2]Department of Advanced Electromagnetics, Ilmenau University of Technology, Germany, [3]University of Niš, Faculty of Electronic Engineering, Aleksandra Medvedeva 14, 18000 Niš, Serbia.

FDTD simulation in wireless sensor antenna application, Bojan Dimitrijević[1]. Bojana Nikolić[1]. Slavoljub Aleksić[1]. Nebojša Raičević[1]. Hannes Toepfer[2,3]. Elena Chervakova[3]. Tino Hutschenreuther[3]. *12th International Conference on Applied Electromagnetics, August 31 – September 02, 2015, Niš, Serbia,* Elektrotechnica & Elektronica E+E Vol. 50. No 9 – 10/2015, Pages 23-27, ISSN 0861-4717. [1]University of Niš, Faculty of Electronic Engineering, Aleksandra Medvedeva 14, 18000 Niš, Serbia, [2]Department of Advanced Electromagnetics, Ilmenau University of Technology, Germany, [3]IMMS Institut für Mikroelekronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau.

Die Zusammenarbeit zwischen der TU Ilmenau und dem Institut für Mikroelektronik- und Mechatronik-Systeme – Garant für eine erfolgreiche Überführung von Ergebnissen der Grundlagenforschung in Produkte kleiner und mittlerer Unternehmen, Hans-Joachim Kelm[1]. Christoph Schäffel[1]. Frank Spiller[1]. *60 Jahre Maschinen- und Gerätebau von der Fakultät für Feinmechanik Optik an der Hochschule für Elektrotechnik zur Fakultät für Maschinenbau an der Technischen Universität Ilmenau,* Jenaer Jahrbuch zur Technik- und Industriegeschichte, Bd. 18 (2015), Seite 481 – 497, ISBN: 978-3939718895, [1]IMMS Institut für Mikroelekronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Application of Wireless Sensors Within a Traffic Monitoring System, Hannes Toepfer[1,2]. Elena Chervakova[2]. Marco Götze[2]. Tino Hutschenreuther[2]. Bojana Nikolić[3]. Bojan Dimitrijević[3]. *International 23rd Telecommunications Forum, TELFOR 2015*, Pages 236 – 241, invited paper, ISBN: 978-1-5090-0055-5, Serbia, Belgrade. [1]Department of Advanced Electromagnetics, Ilmenau University of Technology, Germany, [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, [3]University of Niš, Faculty of Electronic Engineering, Aleksandra Medvedeva 14, 18000 Niš, Serbia.

Multiphysics Modeling of BAW Filters, A. Tag[1]. V. Chauhan[1]. R. Weigel[1]. A. Hagelauer[1]. B. Bader[2]. C. Huck[2]. M. Pitschi[2]. D. Karolewski[3]. *IEEE International Ultrasonics Symposium (IUS), 21 – 24 Oct. 2015*, DOI: dx.doi.org/10.1109/ULTSYM.2015.0115, ISBN: 978-1-4799-8182-3, Taipei, Taiwan. [1]Institute for Electronics Engineering, University of Erlangen-Nuremberg, Cauerstr. 9, 91058 Erlangen, Germany. [2]Advanced Development, TDK Corporation, Anzingerstr. 13, 81617 Munich, Germany. [3]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ilmenau.

Temporal Decoupling with Error-Bounded Predictive Quantum Control, Georg Gläser[1]. Gregor Nitsche[2]. Eckhard Hennig[3]. *Specification and Design Languages (FDL), 2015 Forum on, 14 – 16 Sept., Barcelona, Spain, (Best-Paper-Award)*. DOI: dx.doi.org/10.1109/FDL.2015.7306358. [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [2]OFFIS – Institut für Informatik Oldenburg, Germany. [3]Hochschule Reutlingen, D-72762 Reutlingen, Germany.

An Ultra-Low Power Capacitance Extrema and Ratio Cetector for Electrostatic Energy Harvesters, Benjamin Saft[1]. Eric Schäfer[1]. Alexander Rolapp[1]. Eckhard Hennig[2]. *41th European Solid-State Circuits Conference ESSCIRC, 14 – 18 Sept. 2015*, Pages 245 – 248, DOI: dx.doi.org/10.1109/ESSCIRC.2015.7313873, ISBN: 978-1-4673-7470-5, Graz, Austria, [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [2]Hochschule Reutlingen, D-72762 Reutlingen, Germany.

6D planar magnetic levitation system – PIMag 6D, Christoph Schäffel[1]. Michael Katzschmann[1]. Hans-Ulrich Mohr[1]. Rainer Glöss[2]. Christian Rudolf[2]. Carolin Walenda[2]. JSME Mechanical Engineering Journal, DOI: dx.doi.org/10.1299/mej.15-00111, 16.10.2015. [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [2]Physik Instrumente (PI) GmbH & Co. KG, Karlsruhe, Germany.

Passive 350 GHz Video Imaging Systems for Security Applications, E. Heinz[1]. T. May[2]. D. Born[2]. G. Zieger[1]. S. Anders[2]. V. Zakosarenko[1]. H.-G. Meyer[2]. C. Schäffel[3]. Journal of Infrared, Millimeter and Terahertz Waves manuscript No., DOI: dx.doi.org/10.1007/s10762-015-0170-8, Online ISSN: 1866-6906, Print ISSN: 1866-6892, Volume 36, Number 7, July 2015. [1]Supracon AG, D-07751 Jena, Germany. [2]Leibniz Institute of Photonic Technology e. V., D-07745 Jena, Germany. [3]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Instandhaltungstaugliches Messgerät, Dipl.-Ing. Paul Büschel[1]. Prof. Dr.-Ing. Axel Sikora[2]. Dipl.-Inf. (FH) Manuel Schappacher[2]. Dr.-Ing. Tino Hutschenreuther[3]. Dipl.-Inf. Thomas Elste[3]. Dipl.-Ing. Sebastian Uziel[3]. Studie Nr. 10/2015, Abschlussbericht, DFAM, Deutsche Forschungsgesellschaft für Automatisierung und Mikroelektronik e. V., ISBN-Nr.: 978-3-8163-0676-4. [1]Lehrstuhl für Mess- und Sensortechnik, Fakultät für Elektro- und Informationstechnik, Technische Universität Chemnitz, Reichenhainer Straße 70, 09126 Chemnitz. [2]Lehrstuhl für Embedded Systems und Kommunikationselektronik, Fakultät Elektrotechnik und Informationstechnik, Hochschule Offenburg, Badstraße 24, 77652 Offenburg. [3]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau.

Systematischer MEMS-ASIC-Designflow am Beispiel eines Beschleunigungssensors, Dominik Karolewski[1]. Jenny Klaus[1]. Raiko Pevgonen[1]. Ralf Sommer[1]. ISBN: 978-3-86386-914-4, Pages 9 – 14, Proceedings/EdaWorkshop 15, May 19 – 21, 2015, Dresden, Germany. [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

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Modeling of BAW filters for system level simulation, Dominik Karolewski[1]. Christoph Schäffel[1]. A. Tag[2]. V. Silva Cortes[2]. A. Hagelauer[2]. G. Fischer[2]. Microwave Conference (GeMiC), 2015 German, 16 – 18 March 2015, Page(s) 410 – 413,DOI: dx.doi.org/10.1109/GEMIC.2015.7107840. [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [2]Institute for Electronics Engineering, University of Erlangen-Nuremberg, D-91058 Erlangen, Germany.

High-Frequency Performance of GaN High-Electron Mobility Transistors on 3C-SiC/Si Substrates With Au-Free Ohmic Contacts, Wael Jatal[1]. Uwe Baumann[2]. Katja Tonisch[1]. Frank Schwierz[1]. Jörg Pezoldt[1]. Electron Device Letters, IEEE, Volume:36, Issue: 2, Page(s) 123 – 125, DOI: dx.doi.org/10.1109/LED.2014.2379664. [1]Inst. für Mikro-und Nanotechnologien, Tech. Univ. Ilmenau, Ilmenau, Germany. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Publications in journals

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Drahtlos-Sensorplattform zur Verkehrsdatenerfassung, Marco Götze[1]. Embedded Design, V/2015, 17.09.2015, online: www.embedded-design.net. [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

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MEMS2015 – Schaltplan-basierter Entwurf von MEMS für Anwendungen in Optik und Robotik, Tobias Maier[1]. R. Eid[2]. Volker Boos[3]. Alexander Müller[4], Ralf Popp[5]. Newsletter edacentrum 01/02 2015, Seite 5– 23. [1]Robert Bosch GmbH, Germany, [2]Technische Universität München, Germany, [3]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany, [4]X-FAB Semiconductor Foundries AG, Germany, [5]edacentrum, Germany.

Presentations and Posters

A Flexible Sensor Platform for Traffic Applications, Elena Chervakova[1], Sven Engelhardt[1]. Marco Götze[1]. Michael Rink[1]. Axl Schreiber[1]. *DASIP 2015, Conference on Design & Architectures for Signal & Image Processing, 23.09.2015 – 25.09.2015, Cracow, Poland, (Best-Demo-Night-Award)*. [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Automatic Annotation of Properties to ESL SystemC Models and Accelerated Simulation, Georg Gläser[1]. Eckhard Hennig[2], *Specification and Design Languages (FDL), 2015 Forum on, 14 – 16 Sept., Barcelona, Spain*, [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [2]Hochschule Reutlingen, D-72762 Reutlingen, Germany.

Enhancing Superconductive Sensors and Detectors with Superconductive Digital Electronic Components – A Step Towards System Integration, Hannes Toepfer.[1] *Second International Scientific Symposium "Sense. Enable. SPITSE.", 22.06.2015 – 26.06.2015, Electrotechnical University "LETI" St. Petersburg, Russia, Keynote-Speaker.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Design and Implementation of an Algorithm for a Low-energy and Low-cost Mobile Inertial Measurement Unit, Using Accelerometer, Gyro- and Magnetic Field Sensors, Julian Meier[1]. Hannes Toepfer[1]. Tino Hutschenreuther[2]. Elena Chervakova[2]. *Second International Scientific Symposium "Sense. Enable. SPITSE.", 22.06.2015 – 26.06.2015, Electrotechnical University "LETI" St. Petersburg, Russia.* [1]Department of Advanced Electromagnetics, Ilmenau University of Technology, Germany. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Integration of 802.15.4 based wireless sensor networks into existing intra-vehicle networks, Silvia Krug[1]. Elena Chervakova[2]. Hannes Toepfer[2]. Jochen Seitz[1]. *Second International Scientific Symposium "Sense. Enable. SPITSE.", 22.06.2015 – 26.06.2015, Electrotechnical University "LETI" St. Petersburg, Russia.* [1]Communication Networks Group, Ilmenau University of Technology, Germany. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Seamless Design Methodology for heterogeneous Systems – Challenges for research, education, industry and EDA, Ralf Sommer[1], *Design Automation Conference (DAC), 07. – 11.06.2015, Panel: "The needs and expectations of a fruitful industrial and academic cooperation", San Francisco, USA.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Verkehrsdatenerhebung mit drahtlosen Sensornetzwerken zur Erweiterung der Datenbasis für die Verkehrslagemodellierung in der Stadt Erfurt, Wolfram Kattanek[1]. Marco Götze[1]. *Fachtagung Verkehrstechnik zur Hausmesse Dresden Elektronik, 21.05.2015, Dresden.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Techniques for Identifying the Analog Coverage, Georg Gläser[1]. Lukas Lee[2]. *eda-Workshop 2015, 19.05.2015 – 21.05.2015, Dresden, Germany.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [2]LU Hannover, Germany.

Concept of a quick-change-system for an industrial force sensor with an improved signal to noise ratio, Jörg Mämpel[1]. Eric Markweg[1]. Raiko Pevgonen[2]. Olaf Mollenhauer[1]. *Smart Systems Integration 2015 (SSI 2015), 10.03.2015 – 12.03.2015, Kopenhagen, Dänemark.* [1]TETRA Gesellschaft für Sensorik, Robotik und Automation mbH. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

FPGA-based Hardware Acceleration of Analog/Mixed-Signal SystemC Models, Georg Gläser[1]. Eckhard Hennig[1]. Vojtech Dvorak[2]. *DATE 2015, 09.03.2015 – 13.03.2015, Grenoble, Frankreich.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [2]University of Brno, Czech Republic.

Integrierte Frontend-Schaltung für einen elektronischen Energy-Harvester, Benjamin Saft[1]. Eric Schäfer[1]. André Jäger[1]. Alexander Rolapp[1]. Eckhard Hennig[1]. *17. Workshop Analogschaltungen, 05.03.2015 – 06.03.2015, TU Darmstadt.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Evaluierung und Test von HF-CMOS-Modulen, Einsatz von flexibel konfigurierbaren Testsystemen (PXI), Björn Bieske[1]. Klaus Heinrich[2]. *Testmethoden und Zuverlässigkeit von Schaltungen und Systemen (TUZ 2015), 01.03.2015 – 03.03.2015, Bad Urach.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [2]XFAB-AG, Germany.

Test von HF-Multiplexern für hohe Spannungen, Entwicklung einer Testmethodik für Schalter bis 100 V und 100 MHz, Björn Bieske[1]. Michael Meister[1]. Dagmar Kirsten[2]. *Testmethoden und Zuverlässigkeit von Schaltungen und Systemen (TUZ 2015), 01.03.2015 – 03.03.2015, Bad Urach.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [2]XFAB-AG, Germany.

Granted Patents

DE102012217853B4 "Anordnung zum Erzeugen eines definierten Abstands zwischen Elektrodenflächen auf integrierten Bauelementen für chemische und biochemische Sensoren" der Erfinder Holger Pless, Frank Spiller, Alexander Rolapp, W. Einbrodt, K. Bach, Volker Bornmann.

DE102013114046B4 "CMOS-Thyristor basierte Verzögerungselemente für den Mikro- bis Milisekundenbereich mit sehr geringer Energieaufnahme" der Erfinder Benjamin Saft, Eric Schäfer, André Jäger.

DE102008050540B4 "Anordnung zum Verarbeiten eines analogen Sensorausgangssignals mindestens eines optischen Sensors" des Erfinders Sebastian Uziel.

DE102011016304B4 "Vorrichtung für einen Mehrkoordinatenantrieb" der Erfinder Dominik Karolewski, Michael Katzschmann, Rene Theska, Torsten Erbe, Christoph Schäffel, Norbert Zeike, Frank Spiller, Hans-Ulrich Mohr.

DE102010014663B4 "Vorrichtung zur Positionsbestimmung eines Läuferelementes in einem Planarantrieb und dergleichen Bewegungssystem" der Erfinder Christoph Schäffel, Hans-Ulrich Mohr, Dominik Karolewski, Steffen Hesse, Michael Katzschmann.

DE102007007247B4 "Anordnung und Verfahren zur Verhinderung der Wärmeleitung zwischen einer Wärmequelle und einer temperatursensiblen Baugruppe" der Erfinder Christoph Schäffel, Norbert Zeike.

Disclosed patent applications

DE102013113378A1 "Verfahren und Schaltung zum Bestimmen des Zeitpunkts eines Extremums einer sich zeitlich verändernden Kapazität" der Erfinder Benjamin Saft, Eric Schäfer, André Jäger.

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Research Strategy:

IT system

IMMS connects IT to the real world:

- Open- and closed-loop controls
- Signal processing, evaluation
- System integration
- Communication
- Actuator systems
- Sensor systems

Real world (physical processes)

Subjects of research:

- Energy-efficient and energy-autonomous cyber-physical systems (CPS)
- Micro-electro-mechanical systems (MEMS)
- Integrated sensor systems for biological analysis and medical technology
- Electromagnetic direct drives with nanometre precision