IMMS

ANNUAL REPORT

2017

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Frontispiece: Battery-less RFID chip (center) developed at IMMS to transmit measurement data through containers and liquids over distances of up to four centimetres. Transponder substrate and packaging: microsensys. Photographs and composition: IMMS.

Foreword

Prof. Dr. Ralf Sommer and Dipl.-Ing. Hans-Joachim Kelm. Photograph: IMMS.

Thank you for your interest in IMMS. As in previous years, our Institute has been intensely active in 2017, 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. This future-oriented work will help steer leading themes (Industry 4.0, Energy Efficiency, Life Sciences, and the Digital Society) as we forge ahead with them 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 2017 achievements. Reports on our scientific work at a leading international conference shone in the Competition Runner-up prize. 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.

Use this column to navigate in the PDF file...

...example: the "Leading themes" chapter...

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Public funding by our 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.

Use this column to *navigate* in the PDF file…

… or to access *more detail.*

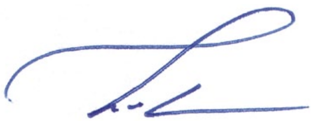
Our thanks go, too, to the Ilmenau University of Technology for superb cooperation, which constantly enriches our work, and, more than that, brings such close research collaboration that synergy effects are felt in both establishments right across the boundaries between disciplines.

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
Scientific Managing Director



Dipl.-Ing. Hans-Joachim Kelm
Financial Managing Director

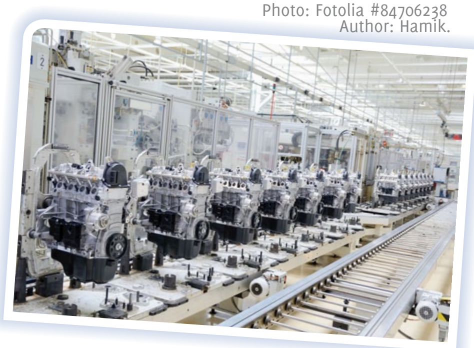
Annual reports for other years at www.imms.de.

IMMS' contributions to the leading themes Industry 4.0, Life Sciences and Energy Efficiency

The research and development activities of IMMS are characterised by the need for technological contributions to the solution of societal challenges such as environmental protection, energy and resource efficiency, health and safety in industrial, public and private spaces. IMMS focusses its research topics and competencies on the leading themes Industry 4.0, Life Sciences and Energy Efficiency. The Institute concentrates on fields of application and target industries in which the integration of electronics, mechatronics and software into intelligent system solutions harbours high innovation and growth potential. These are in particular automation technology, medical technology and life sciences, environmental and traffic technology as well as the semiconductor industry.

In 2017, IMMS expanded its website to include the presentation of these leading themes and complemented it with the respective research and development topics, projects, publications, network activities, reports and dates.

Photo: Fotolia #84706238
Author: Hamik.



Industry 4.0

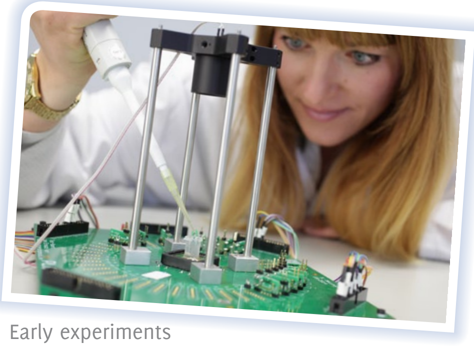
IMMS works on "Industry 4.0" network solutions to acquire, process and communicate measurement and control data for the automation and the open/closed-loop control of machines and industrial plant.

For this purpose, IMMS develops energy- and resource-efficient sensor systems, mechatronic precision actuators, embedded hardware/software components and systems. These systems communicate in real time through data networks with the real world and are being designed for users to implement complex automation solutions and to create efficient value chains.

More on Industy 4.0 at www.imms.de.

The Institute is continuously exploring novel approaches for such cyber-physical systems. These smart solutions unite electronics, mechatronics and software to open up a high potential for innovations and the door for new applications.

IMMS connects microelectronics and life sciences for diagnostic systems



Early experiments to contribute to integrated systems of personalised cancer diagnosis. Photograph: IMMS.

IMMS' life science focus is the research and development of application-specific integrated electronic circuits (ASICs) and sensor systems for quantitative rapid tests and in-vitro diagnosis and for the monitoring of therapeutic progress. The novel systems bring closer a future of point-of-care testing for, among other things, early cancer diagnosis, which is fast, reliable, cheap and largely automated.

IMMS therefore builds upon its multi-parameter microelectronics-based platforms and harnesses off-the-shelf, reasonably priced fabrication techniques and CMOS technology, incorporating them into innovative diagnostic systems. One important research focus of IMMS is the integration of a variety of detection principles into a single electronic sensor chip which can be used to measure biological and chemical features. IMMS works in close conjunction with its life science partners to match the systems to their application, for instance by providing interfaces that are made of biocompatible materials or by accommodating the packaging.

IMMS pools expertise for life science applications of its partners

IMMS works on solutions for harsh conditions and for high-precision applications. It develops energy-efficient, robust and biocompatible electronic sensor and actuator systems. Such systems are able, for example, to acquire, to process and to send data out of implants, fluids or humid environments over years. Furthermore, IMMS develops high-precision drives for use in medical technology and for a particle-free manufacture of biotech products with a precision less than one nanometre.

More on Life Sciences at www.imms.de.

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Providing applications with energy efficiency

Tests for the connection of an energy harvesting module for the autonomous power supply of CPS. Photograph: IMMS.

Here, the work of IMMS focuses on solutions that will help reduce power consumption, use resources more efficiently and preserve the environment. The IMMS developments are being used particularly in sectors with high energy demand, which by their nature have high potential for savings. Instances are the processing industries, transport and facility management.

Providing energy efficiency in the system itself

Here, IMMS conducts research and development on systems which of themselves are energy-efficient and on energy supply solutions for those systems. Amongst other things, this work is enabling for innovative, complex and distributed energy-autonomous control and automation systems. Such systems will underpin "Industry 4.0", progressing industrial production. IMMS also implements ultra-low-power solutions, in this case pushing the physical limits as far as they will go. An example is the energy efficiency in a system which relies on preventing heat generation and contributes to the nanometre precision of direct drives.

More on Energy Efficiency at www.imms.de.

Working hand in hand with the Technische Universität Ilmenau

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Being an affiliated institute of the Technische Universität Ilmenau (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 2017 saw IMMS working on shared research projects with 21 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, with nodes in the semiconductor industry, in life sciences and in automotive, environmental and transport-associated engineering. IMMS plays a part, too, in regional and national innovation networks and industrial clusters. Valuable impetus is given by the groupings. They are the chance to pool skills, use partners' technology and develop joint marketing strategies.

Joint projects

NanoFab* graduate college begun

13 PhD students have been working in the NanoFab Research Training Group (RTG) 2182 since April 2017 on a project funded for 4.5 years by the DFG (German Research Council). IMMS has one of the researchers; the work is on tip-based and laser-based three-dimensional nanofabrication techniques applied to large (macroscopic) areas. The supervisors of the PhD students are teaching and research staff of Ilmenau TU and IMMS under the leadership of the Institute of Process Measurement and Sensor Technology which is concerned with sensors and process measurements in manufacturing in the Mechanical Engineering Faculty.

More detail on NanoFab at www.imms.de.

Robust satellite signal receiving despite interference – KOSERNA* follow-up project

The outcome of the KOSERNA research project is a compact satellite receiver system for robust navigation applications, for which IMMS developed the front-end circuit on behalf of the Department of Radio Frequency and Microwave Technology. IMMS has extended the frontend circuit and transferred the ideas researched in the predecessor project (KOMPASSION), considerably improved the robustness against interference and deception signals and contributed to further reducing the size of the receiver unit. In the planned joint follow-up project, the solutions for safety-relevant applications will be optimised.

More detail on KOSERNA at www.imms.de.

DFG MUSIK* research group – MEMS design and system simulation

IMMS is transferring amplification, control, oscillation and switching properties of micro-electromechanical systems (MEMS) into complex RF circuits as a member of the MUSIK research group. In close cooperation with the Ilmenau TU, IMMS researches MEMS properties as building blocks of high-frequency systems. IMMS develops concentrated fundamental blocks or library elements that serve as the basis for system simulation, including thermal aspects.

Green-ISAS* research group

Together with the Department of Electronic Circuits and Systems, IMMS is at work on new methods and technologies to expand sensor-actuator systems for use in autonomous Industry 4.0 components in the context of the Green-ISAS research group. Basic solutions with very wide applicability are being researched and developed. The basic modules will be yoked together to achieve highly efficient design, construction, testing and operation of new systems. In new combinations, these systems with characteristics of independent intelligence, networking capacity and energy autonomy will be set up and validated in two demonstrators.

Fast-wireless* research project

In the fast-wireless research project, IMMS has been working 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, as a result, support the Internet of Things and Industry 4.0 in real time with true reliability.

IMMS contributes to the "Mittelstand 4.0" (SME 4.0) Competence Centre Ilmenau*

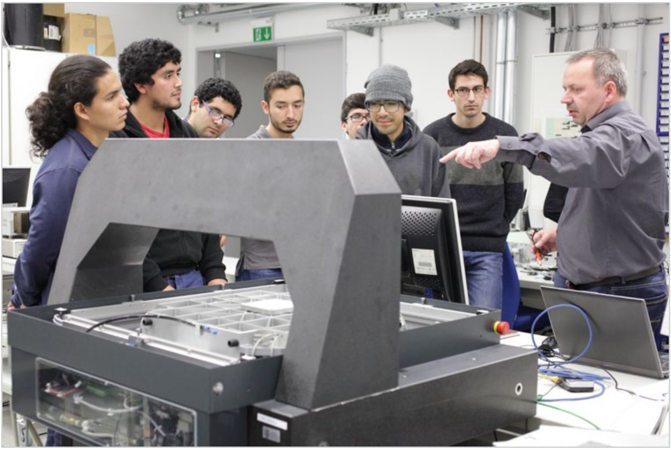
The IMMS contribution is, as the "Model Factory Migration", to give impetus to the introduction of Industry 4.0 technology for the improvement of plant and processes. Machinery and systems can be retrofitted with wireless and networked sensors, for example, and data can be determined and processed for the development of innovative diagnostic, maintenance and service concepts. Thanks to universal electronic platforms for Industry 4.0 components and open source software, real-time solutions can be implemented quickly and cost-effectively.

More on the MUSIK project at www.imms.de.

More on the Green-ISAS project at www.imms.de.

More on the fast-wireless project at www.imms.de.

More on the SME 4.0 project at www.imms.de.



In 2017, over 40 Ilmenau TU student visitors from the DAAD-sponsored South American Young Engineers programme took advantage of the laboratory tours at IMMS to discover suitable internships and support offers.

Photograph: 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 involved in teaching not only in foundation subjects and the MSc courses, but also, jointly with IMMS as a whole, in the Basic Engineering School, a practically oriented outreach of the Technische Universität Ilmenau. With its opportunities for practical experiment in close conjunction with industry and with practical placements, guided tours and such keynote events as the Long Night of Technology (Lange Nacht der Technik) on the Ilmenau campus, IMMS contributes to student training and motivation. In 2017, for example, over 40 student visitors from the DAAD-sponsored South American Young Engineers programme took advantage of the laboratory tours at IMMS to discover suitable internships and support offers.

Research subjects for students at www.imms.de.

In the Kinderuni (Children’s University), a yet younger generation received the attention of IMMS and the University. Professor Sommer gave a lecture entitled ”Pictures, Sounds, Numbers – How does my mobile learn to play?“. He demonstrated to more than 600 children between 8 and 12 years old by means of interactive experiments how a mobile game is created and how sounds, monster voices and images are generated and processed into a program.

The mobile kit to test chips that work with high precision at 300°C and make industrial processes more efficient is the result of a Bachelor's dissertation supervised at IMMS and was presented by the graduate and his supervisor at the Long Night of Science on 3 Nov 2017 in Erfurt. Photograph: IMMS.

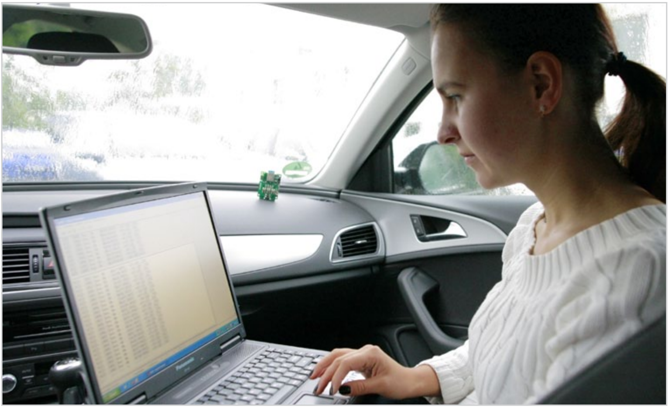
Encouragement of young academics at IMMS – combination of theory and practice

IMMS makes a practice of inviting students of engineering subjects to take aspects of the Institute's current research projects as challenging, useful academic material on which to base practical placements or dissertations for Bachelor's and Master's degrees. Thus, IMMS researches impart theoretic in-depth knowledge of methods for an early combination with a practical implementation in applications. Moreover, the Institute offers training courses and guided tours of the establishment.

On an average, each year sees 50 students working at IMMS either as interns or student research assistants or in association with the dissertations they are preparing for their BSc or MSc. In all, the year 2017 saw 41 students being supervised at IMMS. Furthermore, there are 8 IMMS researchers currently pursuing doctoral studies at various universities.

Research subjects for students at www.imms.de.

The fact that we have so high a proportion of students from Ilmenau TU is an indication that our intensive efforts in fundamental education are in the habit of bearing fruit. We think this is why highly motivated, high-flying students find their way to



Graduate testing wireless sensor networks in the automotive environment while working on her MSc dissertation, supervised at IMMS.

Photograph: IMMS.

IMMS, to our great delight. School pupils, too, are given insight into the work of IMMS by means of events and internships or by having their coursework supervised by professionals of the Institute.

Supervised disciplines

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.

Long-term practical training for challenging research subjects

The time periods of two to six months normally available for completing a Bachelor's or Master's dissertation are usually much too short to enable students to work on complex engineering tasks like developing a microelectronic circuit from schematic design through to production and measurement.

Research subjects for students at www.imms.de.

Therefore, our students frequently take up our invitation to get involved early in their degree course by taking a student research assistant or internship position with us. In these they learn the practical skills they will need in addressing real engineering problems in microelectronics, electronic system design and mechatronics they will face when doing their BSc and MSc at IMMS.

Voices of colleagues at www.imms.de.

This means that our students get a particularly comprehensive and realistic insight into both technical content and management of engineering projects over time. On occasion, the long-term relationships the students make with us lead to a full-scale research job at IMMS later.

Scientific Seminar

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 for discussion. The intense and lively academic exchanges initiated in this way cross the subject borders, encouraging new connections to be made and new ideas to be considered.

Infrastructure for students

IMMS has its own internationally competitive infrastructure, fully meeting industrial norms, supporting the design of and experimentation on electronic and mechatronic systems, and underpinning its research work and the preliminary systems qualification processes. This equipment is available for students' work, too.

Voices of young scientists at IMMS

Martin Grabmann, M.Sc.

»When I chose Computer Engineering as my degree subject at Ilmenau TU, I was trying to bridge my two fields of interest, computer science and electrical engineering. IMMS, too, works to the theme of linking IT with real living –"Wir verbinden die IT mit der realen Welt" – a similar interface between disciplines. It was for this reason that I took note of IMMS during my search for an internship with linked dissertation for the BSc. I was already familiar with the institute from Professor Sommer's lectures and its profile had woken my interest from the first. The good experience I gained as an intern and during the writing of my dissertation on system design then reinforced my wish to stay on at IMMS during my MSc studies as a paid part-time student in the microelectronics section.

Martin Grabmann, M.Sc. (centre), in 2017 after the defence of his MSc dissertation, which was supervised at IMMS.

The outcome was incorporated into a publication that was awarded the Competition Runner-up prize at the SMACD 2017 conference. Photograph: IMMS.

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More detail about infrastructure at www.imms.de.

When I was looking for an issue in a currently active research area for my MSc dissertation, I was offered just the right thing in the ANCONA project. Here, innovative approaches were being developed in EDA and I was able to produce an MSc dissertation on ”Methods for Analogue/mixed-signal System-level Sensitivity Analysis“. Sections of the work I did with my supervisor led to a scientific publication. I was very pleased that the paper was accepted for the SMACD conference in Italy and that I was able to present my results there. We were even awarded the Competition Runner-up prize for our joint work.

Having graduated as MSc, I have been employed at IMMS since May 2017 as a researcher in the microelectronics section. My main job is now concerned with verification of mixed-signal ASICs. Verification involves ”challenging“ the chip by putting it through simulation before manufacture to check whether all the specifications and aims have been fulfilled by the design. This challenge in respect of ever more complex systems demands comprehensive understanding of systems and the use of exactly the right methods of abstraction and modelling. For me, it is a source of pleasure when my work contributes to the success of industrial development projects and to the evaluation of new switching concepts, such as for RFID communications or biosensors.

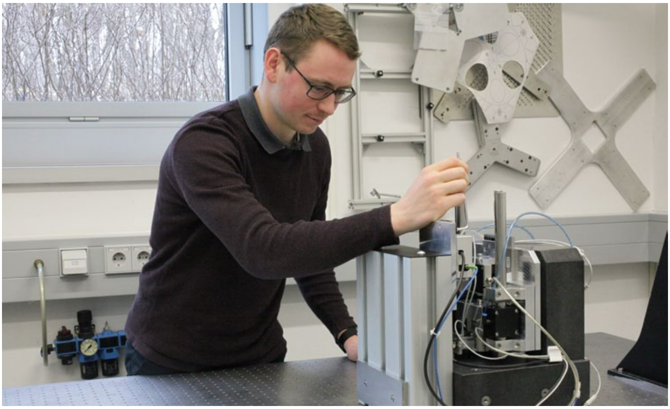
In my everyday work, I particularly value the trusting relationships we have at work as colleagues in an international team. The setting is for me an ideal opportunity for development on the professional and personal front and I hope to benefit from it in future doctoral studies.«

Stephan Gorges, M.Sc.

»In many areas of industry, production development has reached ”saturation point“. Because of the expense of functional improvements, maufacturers can only attempt to pare down their costs. For me, however, there is no professional satisfaction in designing the hundredth exhaust elbow so that it can be manufactured for a few cents less. I would rather set my sights on raising the functionality to the highest technically possible level of quality.

Also, when one is carrying out R&D for small and medium-sized companies, one has the chance to be fully involved from the initial idea through to construction and commissioning of a prototype. Understanding systems is a core competence at IMMS: working there, I have to grasp how all the systems function – drives, transmission, movement, measurement and control systems – so that they all work together in harmony. It is our philosophy not to lose sight of the whole and not to be too

Go to the „Competition Runner-up“ chapter.



Stephan Gorges, M.Sc., with preliminary work at IMMS for a highly dynamic drive system for multi-axis processing of objects with nanometre precision, which he is working on in the graduate college NanoFab.

Photograph: IMMS.

compartmentalised in our thinking. I have to apply all the knowledge I have acquired and, by extending and deepening it, meet new challenges.

As my degree subject was mechatronics, it is these interdisciplinary demands which attract me. In the mechatronics section at IMMS, we deal not only with mechanical-electrical microsystems but also with precision drives. In these highly technical fields there is a need for new thinking to enable macroscopic objects to be moved with precision on the nanometre scale. Ilmenau TU started up the NanoFab graduate college to help improve these extremely accurate machines and to research new processing possibilities in the area of nanoscale product fabrication. The role that IMMS plays in the graduate college enables me to concern myself with the particular demands of vertical movement systems in nanometre positioning and measuring machines.

Go to the specialist articles on precision drives.

Go to the NanoFab chapter.

Why did I choose to come to IMMS? Easy! Having spent an internship at IMMS while studying for the BSc and written my dissertation there, I had already had the experience and pleasure of working here with these colleagues. So it was not a difficult decision to apply for a job with them when I had graduated. The decisive factor was the working atmosphere. Here, I am a member of a team like a family group in which we all level with each other, giving help as needed and learning a lot from each other. Besides, the offices and labs are modern in their equipment and furnishings, so that working conditions are very pleasant. But even outside work, there are frequent activities to share with colleagues, such as barbecues, cycle rides or toboggan races.«

Voices of colleagues at www.imms.de.

Long Night of Sciences in Erfurt 2017. In the lecture "How is a chip created?" there was a live demonstration of design tools and prototypes for guests aged 12 and older. Many pupils and student groups took advantage of the opportunity. The picture shows a Cadence environment with a chip layout from the current ADMONT project.

Photograph: IMMS.

Finding out, trying out and carrying out: a Long Night in Erfurt

When IMMS exhibited in Erfurt's Lange Nacht der Wissenschaften (evening science festival) on November 3rd, 2017, the visitors numbered around 300 in an age range from the primary schoolchild to the pensioner and an academic range from lay person to expert. The visitors included older pupils and students who wanted to look around, listen, try things out and put lots of questions to the IMMS researchers and developers.

"Do-it-yourself" with current R&D projects

IMMS' staff had prepared materials enabling visitors as young as six to have hands-on experience of the results of current R&D work carried out by the Institute with its partners. One exhibit was a means of detecting leaks in compressed air systems using a digital ultrasonic scanner developed by SONOTEC and IMMS for purposes of predictive maintenance. Direct access to indoor data communications by LED was given to the visitors – their starting and stopping of video data transfer in a way projected for all to see. Currently, IMMS is working on the miniaturisation of this technique. It was also possible for visitors to use wireless control of a tablet computer with position sensor to play LEDtris on an LED wall. The game runs on the BASe-Box which is the universal electronics platform developed at IMMS for industrial applications. This form of communication has enabled IMMS to create a variety of solutions around wireless sensor networks. They include building automation, and the monitoring of traffic and environmental conditions. Another possibility was remote control of a model train using washable electronics and knitted switch patches. These knitted, washable remote controls are currently being fur-

More detail on the Long Night: www.imms.de.

ther developed in a collaboration between IMMS and its partner Strick Zella for mass production purposes.

Lectures on chip design with testing

For elder visitors there were three lectures given at intervals under the heading "How is a Chip Created?", so that people learned how a huge number of highly complex functions are packed into a few square millimetres. Then there was the lecture on micro-electronics to recognise cancer early. Listeners heard how and why the surrounding conditions and requirements have to be exactly specified in each particular application before chip development can start, taking bio-analytics as the example. Questions on the subject of chip design were answered by the lecture on how a chip is designed which included live demonstration both of design tools and of prototypes already created. The "testing of high temperature microelectronics" lecture shed light on the work involved in characterisation and testing that is required after chip production. Listeners realised that as elsewhere, there is here usually no standard solution to the problem of testing chip functions. For example, if microelectronics for use at 300°C have to be tested, it will not be long before standard test equipment melts away.

Chips in tough environments – experimental setups in support of the lectures

A number of test situations were exhibited for the lectures, including analysis of biological samples, applied direct to the chip in order to achieve accurate diagnosis of prostate and colon cancer within minutes. It was also possible for visitors to observe an RFID sensor chip without batteries, signalling the measurement data from water at different temperatures. The mobile kit used to test chips that still work efficiently at 300°C and help make industrial processes more efficient served to illustrate more than the content of the lecture on characterisation and testing of chips.

Invitations to do student work at IMMS – www.imms.de/brainwork

The high-temperature testing equipment is, incidentally, the result of a BSc project supervised at IMMS and it was the (meantime) graduate and his supervisor who were the demonstrators. There were two further exhibits that were presented by student colleagues. There were frequent references in the course of the evening to the opportunities of supervision for students at IMMS and the results that have been achieved. Not only that, but during the Long Night, many of the staff members were able to report that it was in a student capacity that they had originally joined IMMS.

More detail on the Long Night: www.imms.de.

Dr.-Ing. Dirk Nuernbergk (left), Analog Design Engineer, Melexis GmbH Erfurt, IMMS' industrial partner. On evaluating the new IMMS methods, Melexis was able to identify the problematic points in three circuits in a very short time.

Photograph: IMMS.

Dr.-Ing. Dirk Nuernbergk, Melexis

"We are a company that has supplied ICs to the automotive industry for more than 20 years. Each year, our research and development team works on dozens of new smart ICs and sensor components. These are needed not only for making cars, trucks and agricultural machinery safer, more reliable and energy-efficient but also to underpin systems in industry, medicine and home automation.

Because our ICs contain ever more blocks of smart functionality, they are ever more complex. More and more functions have to be packed compactly onto a chip surface. In these situations, physical effects may arise which have nothing to do with the desired functionality. An example is crosstalk between neighbouring wires, which often makes it necessary to go through numerous costly and time-consuming iterations to optimise the layout. There are standard tools which serve to report errors but are unable to identify which elements are causing those errors, requiring modification. If commercial considerations demand that chip surface area is kept to a minimum and yet at the same time laid out more compactly, it is like squaring of the circle. Depending on the complexity of a particular circuit, the designer may be confronted with the need to modify manually several hundred or even a thousand potential sources of error and investigate the effects of as many individual coupling situations.

IMMS has come up with a solution. The institute has developed and implemented a program that automatically finds and evaluates critical parasitics even at the design stage. In consequence, layout optimisation, which normally takes so long, is massively accelerated. On evaluating this method, we clearly saw its high potential. In a very short time, we were able to identify the problematic points in three circuits. We are looking forward to using the procedure yet again in the future for our circuit designs."

www.melexis.com

Go to the related specialist article on ANCONA.

Dr. Uwe Stöpel, Funkwerk

"Funkwerk is the international market and technology leader in professional radio systems for rolling stock. We hold and keep this position by allocating a third of our entire staff to our research and development section. We never cease to question our products from the F&E angle, because we want not only to ensure that we stay at the cutting edge but also to be able to offer our customers tailor-made, flexible systems on an ongoing basis.

With understanding for the huge costs involved in the monitoring and maintenance side of logistics, we have also looked for means of monitoring freight trains even as they are moving – in an effective, energy-saving and reasonably-priced manner. This has given rise to the idea of logging data at the locomotive from all sensors in a rake and broadcasting them by radio. In the process, it would be necessary that the occasional interruptions to the radio signal which are to be expected would not impair the system as a whole.

IMMS, with whom we had excellent cooperation as early as 2007 and whose fortunes we have followed with interest meanwhile, has given us real support in developing an appropriate solution. The name of the project is 'fast realtime'. IMMS is in possession of deep knowledge of the potential and the challenge of wireless networks, also of how best to implement autonomous energy systems and to optimise energy use. On the basis of this knowledge, IMMS has developed impressive solutions for the monitoring of traffic and ambient conditions which are already in practical use. As a result, to cooperate with IMMS was an obvious move on our part in the tackling of the issues of maximum reliability and availability in the demanding environment presented by the rail sector.

The result of the collaboration is a prototype which serves to log and monitor freight train functions along the whole length and to transmit the data in real time. IMMS' role has been to develop the wireless communication system which is internal to the train, to deliver the functionality which will monitor all the necessary parameters and to enable the system to work using a minimum of energy. We are very much satisfied with the result – the demonstrator system has been tested on a model train and works impeccably. IMMS has also provided us with simulation software for testing purposes so that we have been able to develop value-added aspects without loss of time. We benefitted from having in IMMS a most competent and committed partner in the specification of software and hardware interfaces. And not only from that: also from their input of ideas as part of the general collabora-

Go to the specialist article on fast-realtime.

tion in meeting our requirements; and from their open-mindedness in finding the solution that matched the need and the environment, with real acceleration in the progress of the project. We could rely on them implicitly as our business partner and wish to express our gratitude for the fine collaboration. Currently, we are weighing up the possibility of testing the prototype on actual freight trains to see whether implementation on the industrial scale could follow successful testing as shared work with IMMS."

Dr. Uwe Stöpel, Head of R&D, Funkwerk Systems GmbH Kölleda.

www.funkwerk.com

Sylvo Jäger, microsensys GmbH

"Microsensys is a developer and manufacturer of RFID software and hardware, which can be used for the checking and optimisation of processes in industrial and medical environments. The focus here is, in particular, on special applications with a need for tailored, extremely well optimised components where sensors are being used.

Sylvo Jäger, Head of Development, microsensys GmbH Erfurt. Photograph: microsensys.

In the context of the funded project with the short name RoMulus for 'robust multisensors for state monitoring in Industry 4.0 applications', we have been in close and constructive collaboration with IMMS to develop a flexible UHF RFID frontend ASIC to serve as the basis for manufacturing sensor transponders. Together we went through the demands on the ASIC which would be made by the later product development. Then we put it all into practice in both the analogue and the digital ASIC design. The knowledge that the IMMS development team possessed in the field of low power and sensors provided an excellent foundation for a sophisticated technological solution.

Go to the specialist article for further RFID solutions.

Besides the cooperation that took place in the funded project, there has also been intensive cooperation on the solving of problems arising from the demands of other customer projects. The technology developed in the shared official project and the many intensive discussions are providing a sound basis for indicating possible joint approaches to customers and then putting them into practice.

For a number of years now, we have been appreciative of our cooperation with IMMS. The Institute is for us an innovative technological partner in our own geographical area, capable of supporting us not only in implementing various development tasks in the ASIC design field but also of coordinating joint projects which benefit from industrial and public subsidy. We are looking forward to building on the success we have already had in development, adding joint solutions to future sophisticated problems."

www.microsensys.de

Prof. Dr. Almuth Einspanier, Leipzig University

"Ever since 2011, we have been researching a process that will enable us reliably to determine the sex of a chicken by hormone analysis before it hatches. We are passionate about this work because we so much want to find a practicable means of ending the wholesale killing of male chicks in the poultry industry.

To validate our endocrinological procedure, we tested more than 10,000 eggs manually as early as 2013. Every single egg was punctured by hand with a tool to remove samples for our investigations. We were able to achieve 98% certain prognosis of sex on the 9th day of incubation. It was clear from the very beginning of the research that not only the actual manual puncture but also the time it took would, in practice, be an almost insuperable hurdle.

Prof. Dr. med. vet. Almuth Einspanier, head of institute at the Veterinär-Physiologisch-Chemisches Institut (Institute of Physiological Chemistry, Faculty of Veterinary Medicine), Endocrinology working group at Leipzig University.

Photograph: SELEGGT GmbH.

In IMMS we found a partner to investigate with us whether mechanised, multiple sampling might be feasible in principle. The outcome was a prototype which, in the design of the machine, makes use of our experience from the manual experiments. When a stack containing 75 eggs is put into it, five eggs in a row are punctured and from each the sample is removed and injected into a well plate. The well plate is full after 15 cycles and can be used for the hormone-based analysis. We tested the prototype in a number of eminently successful experiments. The results were pleasing. More than 2,000 eggs were sampled; the hatching rate was 86.5% and the sampling success 89.5% and the hormone-based sex determination 95% correct.

We were very satisfied with this outcome, to which the very nature of the cooperation, always so positive, contributed. From the very start, information and knowledge was exchanged on a regular basis so that the IMMS staff were immersed in the science, vocabulary and principles of our discipline. As we acquired new knowledge in the course of the project, IMMS always reacted flexibly, finding relevant solutions in response. We should like to express our gratitude to the Institute for the outstandingly constructive collaboration.

After this crucial initial step towards automation we have already succeeded in incorporating the results and experiments into new developmental work with a specialist manufacturer of hatchery equipment.“

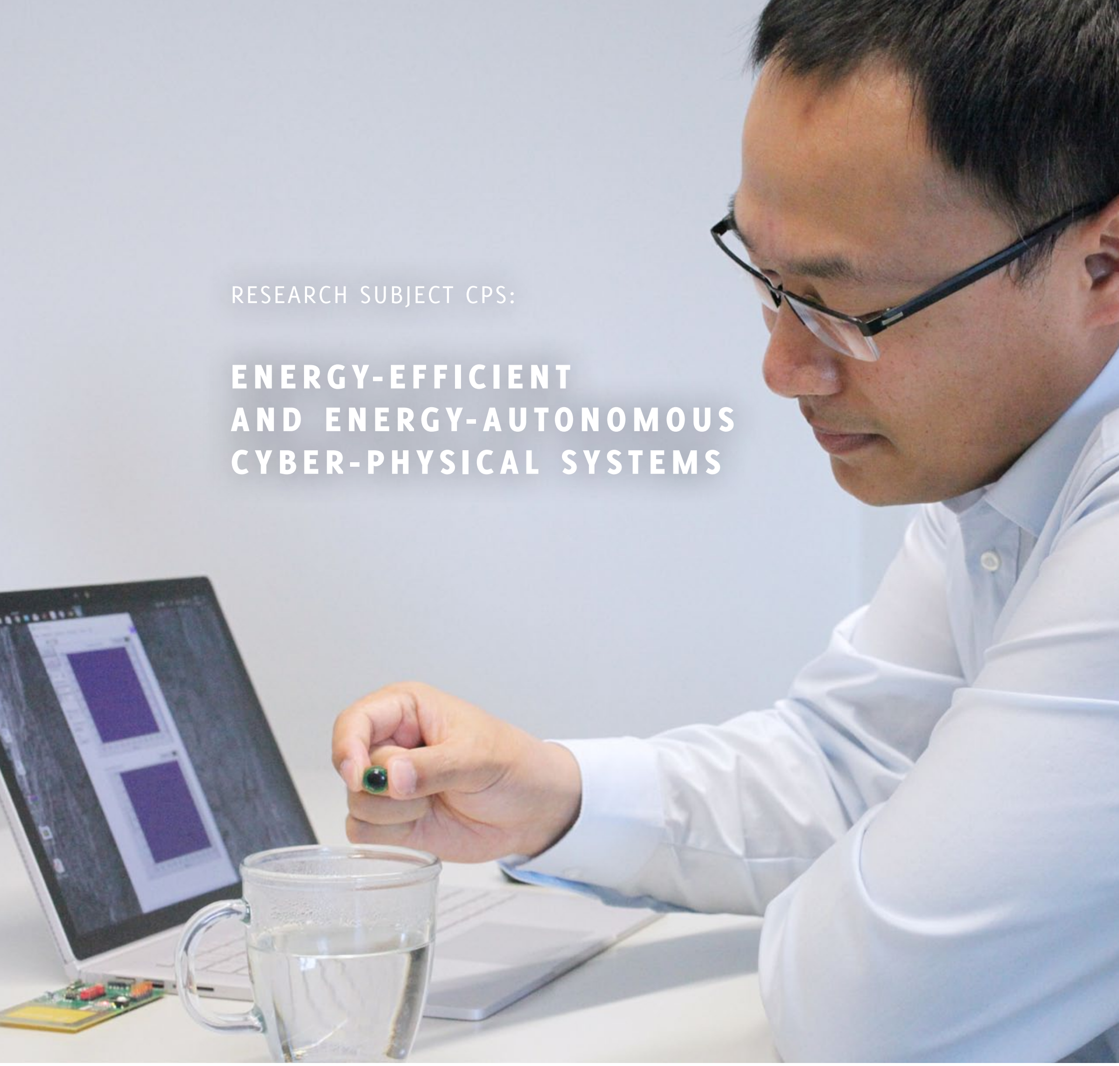
physchem.vetmed.uni-leipzig.de

Go to the specialist article on in-ovo.

More testimonials at www.imms.de.

RESEARCH SUBJECT CPS:

ENERGY-EFFICIENT AND ENERGY-AUTONOMOUS CYBER-PHYSICAL SYSTEMS



This batteryless RFID chip transmits measurement data through containers and liquids over distances of up to four centimeters. Thanks to the ultra-low-power concepts implemented by IMMS, a battery is no longer necessary: The RFID readout unit generates a magnetic field that is sufficient to supply the passive RFID chip with power and to record and transmit measurement data.

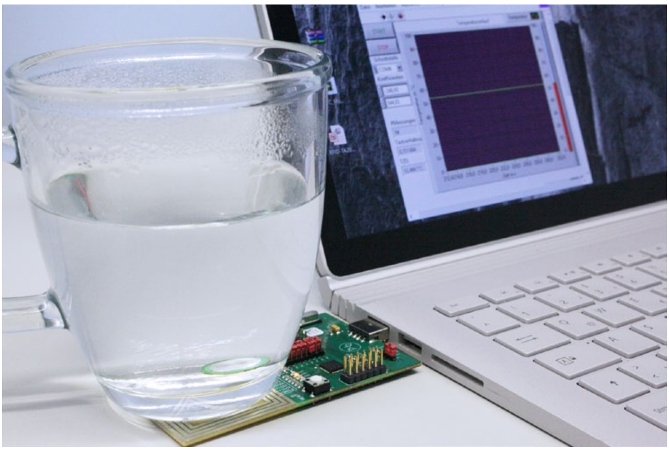
The principle for batteryless RFID sensors pursued in the RoMulus* and ADMONT* projects, among others, is currently being transferred to other measurement parameters at IMMS. This is intended to create the basis for a wide range of applications, e.g. for monitoring bioanalytical processes or industrial processes.

Photograph: IMMS.

Research subject ”Energy-efficient and energy-autonomous cyber-physical systems“

Cyber-physical systems (CPS) 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.



The battery-free RFID chip developed in the ADMONT project measures temperature values in a wide range from 0 °C to 125 °C with a systematic absolute accuracy of ± 0,4 °C which are recorded and processed by an RFID readout unit.

Photograph: IMMS.

More on Industry 4.0 at www.imms.de.

Projects in the CPS field at www.imms.de.

Test setup built in the AgAVE* project for the integration of local industry-4.0-compliant assistance systems in production machinery. Photograph: IMMS.

Highlights of 2017 in our energy-efficient and energy-autonomous systems research

Start of the AgAVE* project

The Fraunhofer IOSB-INA Industrial Automation branch has been working together with IMMS on issues of conformity with "Industry 4.0" for an assistance system to support automatic analysis of networked equipment since march 2017. One building block to underpin complex automation solutions and efficient value chains is the monitoring of machine and plant states in industry. The AgAVE project is committed to providing the **algorithmic foundations** for assistance systems which can be directly integrated into plant networks and analyse them automatically without stopping operations. If using such assistance systems, plant operators will be helped, among other things, to carry out complex analysis of status and breakdowns.

It is the aim of the project that the assistance system should form part of the fourth industrial revolution, Industry 4.0. The role of IMMS is to investigate suitable platforms and/or infrastructures for the **architecture** of such a system.

Since the projected use of the assistance system is in interconnected environments, communication across equipment from different manufacturers must be ensured. The tool intended to enable this is the **Industry 4.0 Administration Shell**, which will carry the main responsibility for data exchange not only between modules and their user but also among the modules themselves. Consequently, IMMS is researching how the administration shell should be structured, what should be its parameters and how they should be communicated. For this purpose, it is primarily OPC UA protocols which are used for communication in Industry 4.0.

For the analysis, it is necessary for data to be channelled into the algorithms. IMMS is investigating and defining **interfaces** for this purpose, to find out the extent to which real-time capacity is necessary and whether it must be guaranteed in every case by OPC UA. It is, for instance, possible to achieve real-time capacity using Time Sensitive Networking (TSN).

The project is being closely followed and supported by the industrial advisory council composed of representatives from pmOne, TE Connectivity Germany, ifm electronic, Weidmüller Interface, iba AG, BN Autmation AG, Riha Wesergold and 3D Schilling.

AgAVE at www.imms.de.

Pure genius: knitted, washable remote controls on MDR TV and for smart cycling wear

In March 2017, the television team from MDR (central Germany's public broadcaster) came to the Zella knitwear company in Thüringen, which is IMMS' business partner in the Smart Jacket project concluded in 2016. The "Einfach genial" (**Pure Genius**) programme, covering new inventions, included a presentation of the jackets we had jointly developed.

The visit was extended to IMMS, where viewers were shown the electronics included in the cloth, why it will work for many years on almost no energy and how it can be programmed using a smartphone. The prototype demonstrated had been set

Details and TV report for this project at www.imms.de.

Shooting of the energy-efficient electronics developed by IMMS in the Smart Jacket* project. Photograph: IMMS.

ZIM Zentrales Innovationsprogramm Mittelstand

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up in particular for the knitted switches and energy-efficient, washable electronics into actual smart clothing which can, for instance, make life easier for the severely disabled and/or provide additional controls for operating industrial machinery. The project partners are meanwhile continuing the development of this prototype to bring it into mass production.

Another project which has included IMMS solutions is **"incyc: Innovative Cycling Solutions"** which ran during 2017. Here, the partners collaborating were HTW Berlin (University of Applied Science), Strick Zella GmbH & Co.KG. (the knitwear factory), TITV Greiz (the Institute for Special Textiles and Flexible Materials), VAUDE Sport GmbH & Co. KG and VCD (the German association for traffic and transport); the project links smart electronics with modern, sustainable, well-designed clothing for urban cyclists. The work led to the design of a cloth module to serve as an indicator: it has LEDs integrated and is worn on the jacket, rucksack or belt. Cyclists can operate the LEDs from a knitted switch in their sweater or jacket or from their handlebars without having to remove their hands. The work at its stage was also presented at the IMMS premises as a functioning prototype in the Long Night that celebrates science in Erfurt.

Ko²SiBus* project startet: continuous and cost-effective signal monitoring for industrial bus systems

More on signal processing at www.imms.de.

For networked systems, so far no continuous monitoring of communication lines

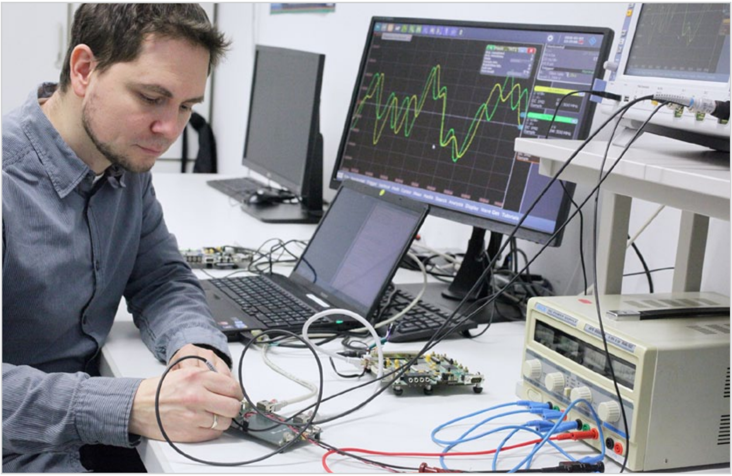
To ensure that highly automated processes run smoothly in industry, states and processes in machines and plant are subjected to permanent monitoring. But until now there has been no continuous monitoring of wired Ethernet-based communication lines for fast and secure data exchange and networking of industrial plant. The reasons are not only the large number of Ethernet cables, but also that most of these cables are concealed and difficult to access so that they will not obstruct production processes. Up to now, investigation of cable breaks and malfunctions has usually had to take place during machine downtime with the aid of additional measuring devices. The cables had to be detached from the system.

Target: trouble-free production through monitoring of wired communication lines

In the Ko²SiBus project, the idea is to minimise these downtimes and maintenance costs by joint work on solutions in collaboration with Chemnitz Technical University

› fast realtime
› ANCONA
› INSPECT
› ADMONT
› PTB
› in-ovo

› Contents
* Funding



In the Ko2SiBus* project novel methods are being developed with which data lines in running industrial plant can be monitored cost-efficiently. The picture shows preliminary investigations. Photograph: IMMS.

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AiF Forschungsnetzwerk Mittelstand

iGF Industrielle Gemeinschaftsforschung

DFAM

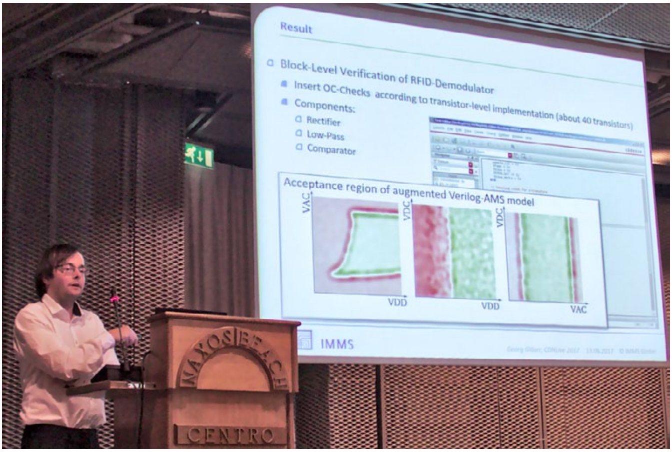
and Offenburg University of Applied Sciences. Thanks to the Ko^{2}SiBus project, the signal quality of wired Ethernet-based installations will in future be continuously and cost-effectively checked during regular plant operation.

This should not only make it easier to plan maintenance work: The new concept should also make it possible to pass on the monitoring data via a uniform and open interface so that it can be easily integrated into customer-specific monitoring frameworks. The solution is to be retrofitted into existing systems, for instance as an Ethernet switch extension, and to be integrated as a feature directly into network nodes of Industry 4.0 systems.

IMMS plans circuits and builds a demonstrator

The role of IMMS is to design an embedded system and develop appropriate circuit concepts. Based on the know-how from developing sensor technology solutions for monitoring industrial plant, for example, in Ko^{2}SiBus a system will be implemented that tracks physical signal parameters using integrated analogue and digital components and reports deviations to a monitoring centre. The functionality is to be tested with a demonstrator which will also be built by IMMS.

Ko^{2}SiBus at www.imms.de.



Presentation of novel methods for design automation, which were awarded the ”Competition Runner-up“ prize at SMACD 2017 and have been developed in the ANCONA* project.

Photograph: IMMS.

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ANCONA* project completed: ”Competition Runner-up“ for design automation methodology

At the ”14th International Conference on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design“ (SMACD 2017) in June 2017, IMMS and its research partners were named competition runner-up for their contribution ”Automated Generation of System-Level AMS Operating Condition Checks: Your Model’s Insurance Policy“.

ANCONA project

The paper describes outcomes from the ANCONA (Analog Coverage in Nanoelectronics), a cluster research project which was successfully completed in June 2017. Together with five universities and research institutions, IMMS was involved in developing computer-aided verification methods with the purpose of easing and accelerating the design of mixed-signal circuits. These are an essential part of the technical foundations for the Internet of Things and Industry 4.0, the ”fourth industrial revolution“. Up to now it has been almost impossible in anything but an experimental set-up to test the interaction between the system components devised for such circuits and any parasitic currents arising. For that reason, the project partners have worked on computer-aided procedures to ensure that reliable functioning of complex systems has been verified even at the design stage.

Award for methods to validate verification results

In the ”competition runner-up“ contribution, a method was presented to automatically extend models for mixed analogue-digital circuit blocks by checks for valid operating conditions or so-called assertions. These checks ensure that the model guarantees a verified verification result. Up to now there has been the possibility that positive verification of a design with purely functional models might turn out to be false and require validation by additional costly simulations.

Automated addition of test conditions

The addition of test conditions to the new approach significantly reduces the likelihood of such a false-positive verification: potential causes of false statements are almost eliminated.

Up to now, such operating condition checks have only been available for transistor circuits. For a larger system, simulation/verification is associated with much more computational effort. Models are therefore usually employed for individual components. These models have not only to match the circuit's function, but also to take into account the ambient conditions such as supply voltage, input signal amplitude and temperature. Previously, this was only possible using complex expressions that have to be input into the model manually – which increases both verification effort and implementation effort. The method presented largely automates this process. In a simulation of the circuit, the user specifies parameters for relevant operating conditions and then these are examined by an exploration algorithm. The result is automatically integrated into the Verilog AMS model of the circuit and can be used directly in further verification.

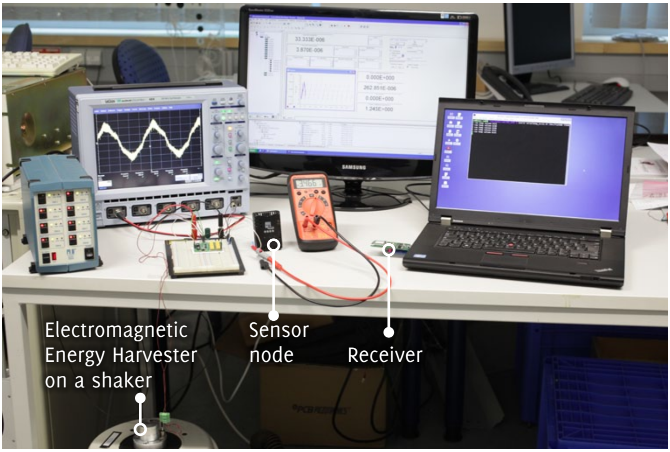
Application in R&D projects

IMMS has used these new methods for electronic design automation (EDA) directly in the verification process for chip development in the ADMONT R&D project, which was carried out in parallel at IMMS. The results of this first sample verification were also presented in the article.

More details on these and other solutions for computer-aided verification methods developed by IMMS in ANCONA are presented in the specialist article on ANCONA.

Go to the specialist article.

More detail on ANCONA at www.imms.de.



Initial demonstrator to investigate energy-autonomous systems and validate the electromagnetic energy harvester design tool.

Photograph: IMMS.

ESF EUROPE FOR THURINGIA EUROPEAN SOCIAL FUND
EUROPEAN UNION European Social Fund
Freistaat Thüringen
Thuringian Ministry for Economic Affairs, Science and Digital Society

Design methodology for electromagnetic energy harvesters and initial demonstrator from the Green-ISAS* research group

Why is design methodology necessary for energy harvesting?

One of the research subjects of Green-ISAS group started in 2016 is electromagnetic energy harvesters. It is hoped that they will enable sensor-actuator systems to be integrated into energy-autonomous components serving Industry 4.0. The vibration of the mechanical moving parts which are ever-present in industrial settings and in logistics can be a source of energy for smart sensors which will serve to monitor both parts and plant. One of Green-ISAS' aims is to achieve rapid design of optimised electromagnetic energy harvesters offering maximum energy exploitation and used for specific applications.

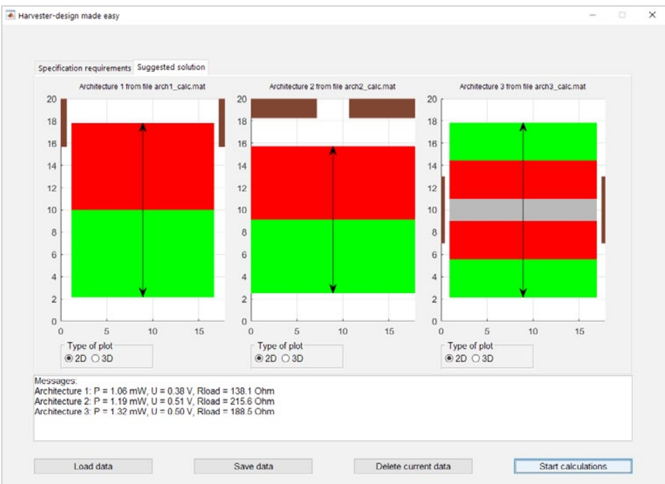
Electromagnetic energy harvesters have many faces

It is eminently possible to adapt electromagnetic energy harvesters to a variety of spatial environments. Harvesters of this type consist in at least one magnet and one coil and generate voltage by induction from a magnetic field as it changes over time. A variety of basic structures is imaginable for the layout of the magnets, coils (and any possible ferromagnetic feedback) and any desired relative movement. To enable the suitability of the various options for the specified requirements to be automatically compared, IMMS is developing rapid, inexpensive design methods for application-specific energy converters.

Design tool for application-specific electromagnetic energy harvesters – interim stage

IMMS developed one type of design methodology for application-specific energy harvesters in 2017 as part of Green-ISAS and has begun to implement it as a design tool in MATLAB®. With the present version of the tool, designers use a graphic interface to enter into the program a number of specification parameters, which could, for example, be size, geometry of the space available, vibration characteristics and power required. The tool takes these figures and compares the various basic structures it has at its disposal, then comes up with a selection of optional designs. Performance of the task relies on a number of parameterised models which analyse and describe the behaviour of the structures. The number of structures available can be increased at any time. The uniform interface that is part of the tool also enables additional basic structures to be added later by the user.

Currently, IMMS is working on a modular layout for the basic structures in the design space. Automatic preselection of possible structures for larger modular arrangements is another focus. For each structure selected, the idea is to input varied dimensions for components, enabling a variety of designs to be generated so that those which meet the desired output considerations (for instance the voltage output or the power) will result. The process serves up to the designer a range of optimised suggestions to be evaluated on particular technical or commercial criteria.

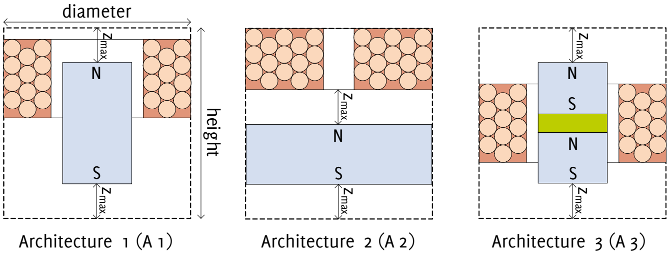


Sample screenshot: optional designs generated automatically using the design tool for electromagnetic energy harvesters developed at IMMS.

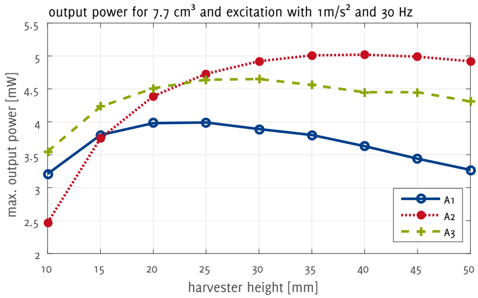
Diagram: IMMS.

Example of exploration of best possible spatial dimensions and evaluation of basic structures (A1,2,3) for electromagnetic energy harvesters.

Diagram: IMMS.



Initial results on comparison of basic structures



Having designed the tool, one of the ways IMMS has used it has been in simulation to investigate what influence the spatial dimensioning has on the power density of vibration-based electromagnetic energy harvesters. There were technical limitations such as the copper fill factor that could be achieved or the minimum gap between coil and magnet (which is determined during manufacture), and in dependence on these one of the features considered was the maximum output power related to the height of the harvester for a variety of volumes. This investigation showed that there is an optimum height related to the volume which enables the power density to be maximised. It was also confirmed that the best basic structure will depend on (among other things) the spatial limit. Overall, the conclusion was that there is no one single best principle for electromagnetic energy harvesters but that the design principle will always be dependent on the actual requirements and the layout will always be specific to these. Consequently, once the building block principle as developed has been fully implemented, the design tool is potentially a lever for efficient design of electromagnetic converters of vibration energy.

Demonstrator for investigation of energy-autonomous systems and design tool validation

In 2017, a device was constructed at IMMS which served as proof of the principle, demonstrating how much progress had been made in developing the individual components of a self-powered system. It is a device that makes it possible to visualise the behaviour of machines and industrial plant in the laboratory. In later stages of the project, it will be used to evaluate whether the prototype harvesters generated automatically with the design tool achieve the desired scavenging behaviour.

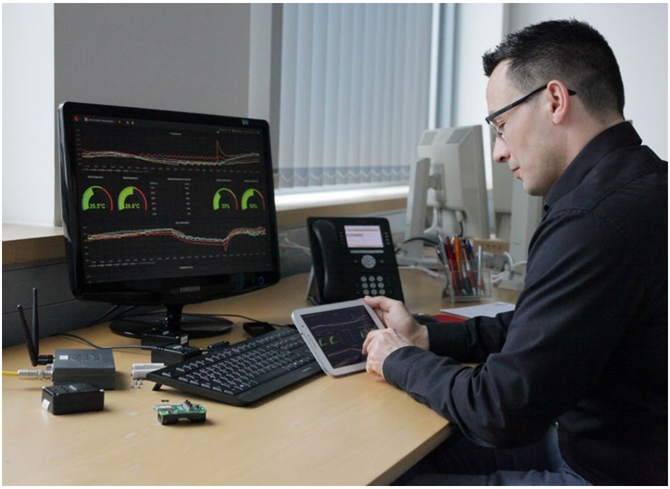
Green-ISAS at www.imms.de.

The interim research results of the Green-ISAS group have been presented internationally: at the Workshop Devices, Materials and Structures for Energy Harvesting and Storage in Oulu, Finland and at the IWK (International Scientific Colloquium) in Ilmenau and the 2nd Green-ISAS status workshop. At a meeting of research groups from Thüringen, conversations with working groups from other universities and research establishments brought up initial thoughts on further national and EU research projects in the field.

KSS*: Automated monitoring of cooling lubricants to protect health and to improve resource efficiency

Since 2017, IMMS has been contributing to a development that should benefit small and medium-sized companies, enabling the fully automatic and continuous monitoring of relevant cooling lubricant parameters in real time and in a quality that is currently only economic for major enterprises. At GFE Präzisionstechnik Schmalkalden, a demonstrator is to be jointly built in the manufacturing area.

Cooling lubricants are used in industry for milling or turning precision parts. One of their purposes is to cool tools and workpieces, reducing friction and thus reducing wear and tear on tools. At one and the same time, the chemical washes away the swarf, binds dust, improves both dimensional accuracy and surface quality of the workpieces and protects these from corrosion. However, checks must regularly be made that the prescribed limits for certain content parameters in what the engineers call the "drilling milk", in order, among other things, to avoid dangers of health.



As a partner of the SME 4.0 Competence Centre Ilmenau* IMMS contributes to solutions for automated monitoring of cooling lubricants to protect health and to improve resource efficiency. Photo: IMMS.

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More on communication solutions at www.imms.de.

Safety first: strict rules, much trouble

The lubricant material can cause aerosol particulate suspensions to accumulate in inspired air. Water-based drilling milk that has not been used for a while may attract bacteria and fungi to settle in it which can cause infections and allergies. As cooling lubricants heat up, carcinogenic nitrosamines tend to form and bacteria to grow. This is the reason for the many and strict restrictions on handling the materials and the limits set requiring their regular testing and maintenance. The rules are laid down in the German federal Technical Rules for Hazardous Substances (TRGS) and the German official industrial accident rules, DGUV 109-003. At present, however, the weekly and daily test routines with monitoring sheets for each machine are often still documented manually.

Add-on sensors automate the prescribed testing and offer new functions

It is the intention to fit suitable sensors to existing machinery by means of which the values can be easily and cost-effectively tracked, called up at any time on a tablet or normal PC and displayed graphically. The benefit will be not only the health and safety parameter monitoring but also long-term analysis, predictive maintenance and the setting of thresholds and warning signals to enable timely intervention in the event of a malfunction. Thanks to such continuous monitoring, it will be possible to use the cooling lubricants for longer periods and reduce the inhibitors usually employed to stabilise the drilling milk. As regards direct measurements in the cooling lubricants, GFE Präzisionstechnik Schmalkalden is currently testing technology for special measuring tasks, which has been developed by a partner company for this purpose.

IMMS upgrades sensors for acquisition, transmission, processing, cloud and visualisation of climate data

In the context of the "SME 4.0 – Competence Centre Ilmenau", one task of IMMS is to contribute additional retrofittable sensors that monitor climate data in production areas, supplying complementary information around the deterioration of drilling milk. In the case of GFE, IMMS will implement the solution for wired and radio-based data transmission. An energy-efficient industrial PC will pre-process the environmental data and store it permanently in a cloud-based data platform. IMMS will also implement the web-based graphical output of the measurement data on whatever end devices are required. 2018 should see the results of this work.

KSS at www.imms.de

The work on cooling lubricants is one of the sub-projects (designated KSS) of the "SME 4.0 – Competence Centre Ilmenau" project.

Delivery of the UV water disinfection system, which reduces the use of chlorine in the Ilmenau indoor swimming pool*. IMMS has contributed the remote reading of sensor and system data. Photo: IMMS.

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Using UV and data monitoring to disinfect indoor swimming pool water in Ilmenau

On 11 October 2017, in the presence of the Mayor of Ilmenau, a new means of water disinfection by UV light was launched at the “Am Stollen” swimming pool by IL Metronic Sensortechnik GmbH, Umex GmbH Kirchheim and UV Technik Speziallampen GmbH. At the same time, a demonstration solution for wireless remote reading of sensor and system data was implemented with the support of IMMS as part of Ilmenau’s SME 4.0 Competence Centre.

Water disinfection for indoor swimmers – UV replacing chlorine

In indoor swimming pools, the current state of the art of disinfection is to use chlorine compounds. To enable the proportion of chlorine used and the consequent undesirable side effects to be reduced, companies from in and around Ilmenau have provided the Ilmenau indoor swimming pool with a germicidal UV medium-pressure reactor. Importantly, sensor technology is integrated into this system for permanent monitoring to ensure correct function of the UV radiation source. The sensor data is evaluated locally in IL Metronic’s special monitoring equipment, which reports any deviations or failures of the UV radiation source to the process control centre at the swimming pool.

More on communication solutions at www.imms.de.

Remote readout of sensor and system data with IMMS’ solution

An existing data interface on the measuring system of the UV reactor is used to record, evaluate and store sensor and system data over long periods of time in a simple and cost-effective way. With the help of the compact and energy-efficient “BASe-Box”* industrial PC developed by IMMS, the data is to be transferred using

With the ”BASe-Box“* developed at IMMS, the data of the water disinfection system is connected to the cloud. Photograph: IMMS.

an integrated mobile radio modem to a server and stored there permanently. The data is displayed via a secure internet connection in browsers on any terminal devices such as tablets. The solution not only provides the basis for comparisons of target and actual values together with automatic notification of any deviation, but also supports long-term analyses and predictive maintenance of plant components.

Networking of an overall solution in the IMMS-supported “Model Factory Migration”: the inspiration

It was in the course of the regularly held workshops and meetings on ”Sensors 4.0” which form part of the information and continuing education programs offered by the SME 4.0 Competence Centre Ilmenau that the idea of networking and remotely evaluating local UV monitoring occurred to IL Metronic. The Sensor 4.0 workshops are initiated and conducted by the Model Factory Migration, which is supported by IMMS as a partner of the Competence Center. IMMS has continued to discuss intensively the possibilities of remote readout of sensors and plant components with IL Metronic as a means both of “keeping an eye” on the equipment and of opening up the improvement potential of products and services offered by this specific application.

The swimming pool project at www.imms.de

”Sensors 4.0“ – Ways of gradually introducing digitisation

Workshops to transfer know-how – well received by regional companies

In May, August and November, 2017, a total of 48 companies from the region sent representatives to IMMS, principally to workshops, to be given practical potential solutions that would help them introduce the technologies of Industry 4.0 to improve their machinery and industrial processes. The IMMS experts were acting in their Migration Fab role for the SME 4.0 Competence Center Ilmenau, showing how machinery and equipment can be refitted with wireless and networked sensors so that data can be obtained and processed to underpin new diagnostic, maintenance and service plans. They also showed how everything could be linked via cloud-based services. Participants were taken step by step through all the stages of creating their

Free workshops at IMMS alias Model Factory Migration of the SME 4.0 Competence Centre Ilmenau*: Practical examples show how machines and systems can be retrofitted with networked sensors. Photo: IMMS.

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own first examples using universal electronics platforms for components that are Industry 4.0 compatible, together with open-source software. From the learning they were able to grasp how real-time capable solutions can be put together rapidly at a reasonable price. To quote Steffen Rosipal, N3 Engine Overhaul Services GmbH & Co. KG Arnstadt, "The issues so clearly treated in the workshop were exactly what we are currently facing in our company and need to resolve. The teaching provided potential solutions. We took away with us really interesting new ideas and are certain to come back to the services offered in the Migration Fab alias IMMS." The series of workshops is being continued on another four dates at IMMS in 2018. The subjects will be the connection of upgradable sensors using Linux, networked radio sensors with cloud connection, sensors as Industry 4.0 components, and cloud processing of sensor data.

More on the SME 4.0 project: www.imms.de.

Chances to exchange ideas and experience: regulars' evenings, information sessions, guided tours and more

There were other SME 4.0 initiatives on the part of IMMS besides the workshops, organized for regional companies on the various Industry 4.0 subjects, with regulars' evenings at which IMMS gave its own ideas but also recruited external speakers to stimulate wide discussion extending from product demands and sensors right through to data-based services and relevant business models. In the opinion of Michael Strauß, Controller und Business Analyst at addfinitiy testa GmbH, a small specialist plastics company, "Sensors as a production aid are a huge subject. We are hoping that there will be yet more users in attendance at the next regulars' session in order to exchange experience and check out all the things that are already possible – for example, upgradable sensors. These networking meetings are helping us on the road to success and are a chance to share knowledge.“ The sessions are a combination of guided tours, presentation of demonstrators, chats and other events, all supported by IMMS but at times happening elsewhere, for instance, at BN Automation AG, Ilmenau TU or alongside the ”elmug4future“ technology conference.

From lively exchanges at events to joint activity – the first ideas have been put into practice

There was more than one outcome of the sharing of widely ranging subjects and differing angles on automation and networked systems. One was the depth of the discussions arising among participants, but many of these made immediate use of the opportunity to put ideas into immediate practice or start on their planning. And so as early as summer, 2017, an innovative disinfection plant came into operation at the Ilmenau **swimming baths**. It was the SME 4.0 events that triggered the idea of no longer evaluating the sensor output from the plant on site but doing so via the cloud. The knowledge gained will now be applied in networking other similar plant belonging to the partners, which will then benefit from new trouble-shooting, maintenance and servicing schemes.

Current events at www.imms.de.

The swimming pool project at www.imms.de

Furthermore, yet another undertaking was begun thanks to the SME 4.0 events at IMMS. Here, participants initiated the fully automatic, continuous, real-time monitoring of all the relevant operating and environmental conditions, such as for **cooling lubricants** (designated KSS), for metal-cutting tools using sensors, a luxury only previously available on a commercial basis to major industrial enterprises. Results are expected in 2018.

KSS at www.imms.de

Yet more ideas were launched, such as that of **starting up grouped machinery** in a controlled and energy-saving manner. Members of workshops in 2018 are going to pursue these techniques.

SME 4.0 at www.imms.de.

In the TSN laboratory* funded by the "Land" of Thüringen, IMMS investigates technological limits in the development of data-intensive industrial real-time applications. For example, the behavior of the TSN Time Aware Shaper according to IEEE-802.1Qbv is analyzed with TSN development systems from the company NXP (front right) and methods for simplified parameterization of TSN networks are implemented (see the Monitor). Photo: IMMS.

TSN test laboratory* set up

Individual components hold up the industrial Internet

In the Time Sensitive Networking (TSN) laboratory which it set up in 2017, IMMS is exploring the technological limits to the creation of data-intensive industrial real-time applications.

In the digitisation of production and business processes, close digital networking of physical processes in real time is necessary, and so-called CPPS (cyberphysical production systems) with scalable platforms for data processing must be the result. These CPPSs combine to form an industrial Internet, the technological foundation underlying new digital services and business models and, indeed, Industry 4.0 in general.

However, particularly in data-intensive real-time applications, CPPSs still come up against the technological limits set primarily by restricted bandwidths and possible low communication and data processing capacity in individual components that form part of the overall architecture.

Among the data-intensive applications requiring large amounts of data to be recorded, transmitted and processed in real time are in-process quality control and continuous monitoring and diagnosis of the status of machinery. Other data-intensive tasks are virtual imaging of real processes or ensuring safety and security, as is necessary in human-robot collaboration.

TSN test lab at www.imms.de

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TSN laboratory equipped as research platform

It is for these reasons that the TSN lab has been set up at IMMS with an extensive infrastructure funded by the "Land" of Thüringen. On this research platform, IMMS will carry out fundamental investigations of both system architectures and hardware and software technology, fully exploring with reference to this particularly demanding class of industrial applications, the laboratory will investigate design issues for the essential TSN components: time synchronisation, rules for network packages and rules for communication paths.

The platform contains all necessary components: different types of sensor, edge devices for data pre-processing, communication modules for real-time data transmission, powerful servers as a local cloud where large amounts of data can be processed, the various software licenses and items of laboratory equipment. It is scalable and flexible with regard to the hardware and software technologies used.

Research on systems for Industry 4.0 in the TSN laboratory at IMMS

In particular, the platform supports IMMS research into "real-time communication", the technological continuity communication between sensors and internet-based data processing platforms. Here, the investigation is of "edge computing", the recording and [pre-]processing of data from multi-channel sensors with high data rates and high resolution using energy-efficient embedded systems; also, of "edge devices" involved in time-synchronous and low-latency vertical and horizontal networking between embedded systems and cloud data processing servers. The laboratory also tests in real time the processing and visualisation of high-resolution sensor data and the information generated from it.

More on communication solutions at www.imms.de.

The equipment is used for research work in the FAST realtime, AgAVE and Ko²SiBus projects and serves, besides, as an experimental and demonstration platform. It is also available as an Industry 4.0 test laboratory for the benefit of manufacturers of sensors and automation components and is an essential component of the I4KMU test environment at IMMS.

More on I4KMU: www.imms.de

The edaBarCamp series continued in 2017 with two events

The third edaBarCamp took place as early as December 2017. The series was started in 2016 by edacentrum, OFFIS and IMMS, originating in the ANCONA project's seminars for doctoral students. The cohesion established in these cross-institute meetings during the project which was to end in 2017 was extended in accordance with the BarCamp principle to enable a continuation of regular interactive, open researcher meetings – for a wider circle including undergraduate and postgraduate students, professors, experts from both industry and public service and, indeed, for anybody with an interest in EDA (electronic design automation), microelectronics and system design.

edaBarCamp in December 2017. Photograph: Dieter Treytnar, edacentrum.

Basic edaBarCamp principle: participants design their own participation

In open sessions, each person has the chance to introduce his or her own issue and to enrich the other sessions with his or her thoughts and ideas. There is scope for each person to suggest subjects before and during the camp. There is no programme commitee. The event starts with a listing of the suggested issues so that common interests can be identified within the group. From this list, again as a group exercise, the agenda is set. In this way, every point on the agenda is sure to hit the spot because the early vote has shed light on the attenders' degree of interest in the subjects. These are meetings where no one is allowed to be a "meeting-ee" but must be a "meeting-er": never only passive but a genuinely active member. According to the interest present, sessions can be organised in many ways: interactive workshops, presentations, tutorials, brainstorming, brief hackathons or open Q&A or feedback circles. Documentation is carried out as a shared task and exchanged with other groups, then made available after the event. The communications channels used by the edaBarCamp are the platforms and social media preferred by today's young scientists.

Where is the edaBarCamp as 2017 ends and where is it going?

By the end of 2017 there was an exchange of views and research between and among about 20 campers from Finnish and German universities, research establishments and commercial enterprises on many subjects including open-source EDA tools, virtual platforms, sensitivity analysis at the system level, applications for highly distributed embedded platforms, formal analogue-mixed-signal verification and co-design for sensor-actuator systems reliant on energy harvesting. The series is to continue, there are more BarCamps planned for 2018.

Current events at www.imms.de

Energy demand measurements on prototypes for a low-latency train monitoring system with local radio sensor network. Photograph: IMMS.

Objectives and overview

Freight trains are dragging their feet with digitalisation

Railway trucks differ from other freight transport such as road trucks and planes in that (at present) they can only be monitored in the most rudimentary of ways using smart components. Because they carry such heavy loads and are subject to jolts and traction, rail trucks have different coupling from that used in passenger trains, which makes electrical connection from one truck to the next impossible. Because the couplings are differently constructed, it is not only the insulation of the electrics from rain and dirt which is problematic to transfer from passenger to goods trains. There is the additional complication that freight trucks are uncoupled more often and, besides, coupled and uncoupled manually. As a result, to give impulse to the innovations in rail freight which employ sensors, locators and state-monitoring, there is a need for surveillance systems that can be effectively and economically fitted onto trucks already in use, without its being necessary to reconfigure them during everyday operations.

More on fast realtime at www.imms.de

Mobile communication used already for monitoring, but unreliable

It is already possible for trains to find out for themselves by mobile communication the data that will give them clearance for the next stage of their journey, for example. Currently, the information is gathered from the infrastructure along the line, with all that this means in terms of maintenance. The networked surveillance systems integrated into the train might in future serve to establish freight truck positions and journey times, to check the train has all its trucks, to permit automatic coupling of trucks and to monitor the load and the wheels. There are already systems in existence for the purpose, signalling data for each individual truck to an external monitoring station, in some cases also with an additional GPS receiver. However, on stretches where signal is weak or absent, central data processing will suffer accordingly. Rail services have a two-second target for message delivery, which cannot be comprehensively guaranteed when usign mobile communication.

Extending the approach: surveillance using a local wireless network

This has led the "fast realtime" project to adopt an additional approach and test it by constructing a demonstrator. Here the technique is to link the individual trucks wirelessly via a local sensor network and to do the monitoring internally, in the train. In this way, mobile communications are necessary only for the upstream applications on the railway network.

The aim of the new system has been to monitor the operating parameters such as temperature and vibration levels for every truck on a freight train, also to check the order of the trucks and that none is missing, and to transmit all this data in real time. Such a system has to record events in trains up to 100 trucks long and transmit them to a control centre on a cloud platform in less than 2 seconds, i.e. the system requires more than 100 sensor modules, a data concentrator and a mobile communication access point in the locomotive. The control centre is responsible for many trains.

More on communication solutions at www.imms.de.

This is asking a great deal, for one great problem in trains is that the metallic environment makes radio signalling less than perfect. Another problem is that it is not possible for a communication to be registered by other neighbouring sensor modules as would be the case in classic network tropologies, because the modules are in linear order truck by truck, which means that there is only one possible route for the transmission of a data packet from module to module along the train.

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Solution tested on a model train to be transferred to freight trains

IMMS has created a prototype wireless network of sensors internal to a model train for a monitoring system of the kind described above. The work has involved investigating a low-maintenance, reasonably-priced, easily retrofittable system made up of available hardware and software components for wireless sensor modules. The selection and configuring of these is such that the delays in data transmission known as latency have been kept to a minimum, as is the energy consumption involved in the monitoring tasks. Funkwerk Systems GmbH, IMMS' partner, has developed systems enabling the data assembled in the local wireless sensor network produced by IMMS to be sent by mobile communication to the central, cloud-based monitoring point.

The result is an energy-efficient monitoring system with optimal latency that is capable of forwarding the data from a freight train for processing on a cloud platform within less than two seconds – so that any alterations in state or other events can be checked and evaluated with any necessary automatic triggering of further action.

An additional communication channel between the control point and the wireless modules can be used to pre-process the data in the modules. This partial transfer of smart features into the modules themselves increases the system efficiency, in that less data has to be transmitted. All configuration messages are subjected to confirmation by the modules, which means that communication is assured.

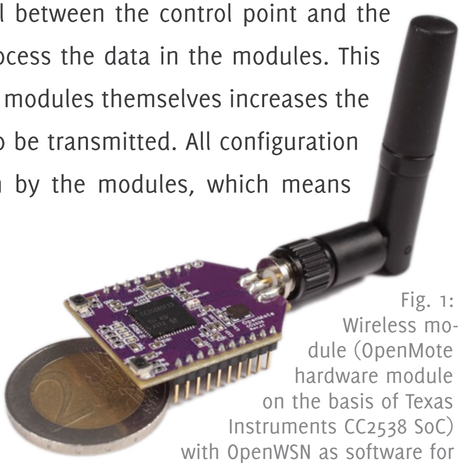

Fig. 1: Wireless module (OpenMote hardware module on the basis of Texas Instruments CC2538 SoC) with OpenWSN as software for the implementation of the network communication stack. Photograph: IMMS.

Details and IMMS' contribution

Wireless sensor modules – hardware, software

Specifications

To monitor an entire train, a wireless sensor module must do a number of **tasks**. It is necessary for the position of every truck in the freight trainset to be clarified and the order of the trucks to be derived from this data. This must happen without reconfiguration of the wireless modules every time the composition of a train is changed. The system requires that modules of equal status automatically form a network – the term used for this is an ad-hoc network.

The order of the wireless modules in the network (this is the **network topology**) is linear. It reflects the order of the trucks in the train, meaning that each module in the network has only two neighbours to relate to (in the case of the first and the last module, only one). This fact eliminates the option of alternative communications partners. All the operating parameters, for both truck and load, must be captured and monitored in real time and any errors also reported in **real time**. If the share of the time for mobile communication necessary for data transfer onto the cloud platform is deducted from the desired time of less than two seconds, there will only be about 1.5 seconds in an ideal case for the internal communication within the train, depending on communication system. In this short time, up to 100 wireless sensor modules will have to communicate their captured data very efficiently from the last to the first truck.

Among other potential problems, for certain data messages from the modules the highest **priority** will apply. In contrast, configuration messages being sent to the modules are static in nature. They make no particular demands on the transfer time and can be stored before being transferred.

Besides the details relating to the individual trucks, the sort of information that is necessary for recognizing the composition of the trainset also has regularly to be captured, then rapidly processed and communicated. If a network topology has formed reflecting the order of the trucks, each wireless module must constantly evaluate its link with the truck in front of it, i.e. the module nearer the engine. The **evaluation parameters** are the strength of wireless signals received or the distance of the preceding truck derived from the wireless communication. If the relevant parameter is no longer within the tolerance limit, there must be recognition that the train has split and this must be reported.

In addition, the modules have to work with high **energy efficiency** because, freight trucks not being coupled together with electric cables, the modules rely on batteries. These batteries should be exchanged in set maintenance periods of six years.

Choice of hardware and software

IMMS deliberated on all these tasks and restrictions, deriving from them the specifications for the wireless sensor modules so as to make a choice of hardware and software. The really crucial factor was to find comprehensive means of energy-saving that were compatible with communication procedures that had a strict time window. It was also important to find basic, reasonably-priced modules that are nonetheless state-of-the-art and capable of optimisation using open-source software for the purposes of the application.

To meet these conditions, IMMS' choice fell on **OpenMote wirless modules** and **OpenWSN network software**, which contains freely available implementation of standard network protocols and constitutes a complete network communication stack. The data flows through layers stacked one above the other, for instance the application, transport or network access layers. There is a simulation environment integrated which permits virtual operation of the network.

The **Open WSN software** is based on 6LoWPAN as a communication protocol for wireless data transfer. As such, it is capable of transferring IPv6 data packets wirelessly. It is thus possible to integrate the wireless network into existing networks without trouble. The radio communication conforms with the IEEE 802.15.4 norm. This standard permits systems which use very low amounts of energy and thus exhaust batteries only very slowly. The 2.4 GHz band, being licence-free, enables reasonably-priced implementation. Channel access is always based on the time window. The access is by time-slotted channel hopping, i.e. with changing frequencies, to avoid collisions between data packets. Energy-saving "sleep states" are possible without risk of missing the arrival of data.

The **tasks** of the wireless sensor modules have been shared across various **services**. Thus, IMMS extended the OpenWSN software by further services, to visualise the order of trucks, monitor external sensors and determine the time taken by messages to arrive. The implementation of these services is **modular**, using defined interfaces with the network stack. This means that the system can be ported more easily into alternative software environments and, what is more, can be transferred without much trouble to other fields of application.

Energy efficiency

As the maintenance interval preferred by the rail freight industry is up to six years, it was necessary to find a battery for the wireless sensor modules that will have adequate capacity, which has to be calculated from the energy consumption of the modules.

Energy requirement, energy model

For an estimate of the energy consumption the activity of the sensor modules was analysed for the various operating phases, particularly in respect of the signalling distance and divided into the modes inactive, transmit and receive. IMMS took twelve sets of measurements from an experimental setup to show the energy consumption of the modules in the individual phases. All measurements were taken under exactly the same conditions; one example is shown in Figure 2. In the statistical evaluation of the measurement sets for three identical modules, sample scattering was calculated and noted. Measurement errors were minimised by using mean values.

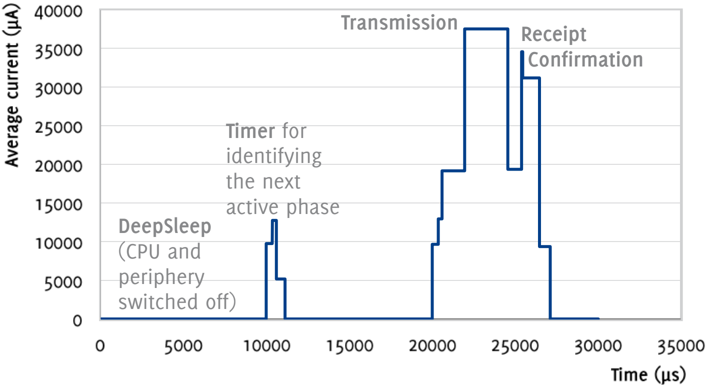

Fig. 2:

Energy consumption of a wireless module when sending a message and receiving confirmation of its receipt.

Diagram: IMMS.

IMMS has developed a **model** for the application scenario showing the timing of the operating phases. In it, the activity of the network stack and of the services implemented was taken into account – in the case of the network stack, the training and operation of the ad-hoc network, in the case of the services the continuous monitoring of the truck order and external sensors. It is possible to set the frequency of the individual phases for a certain period in the model and so to represent the behaviour of the wireless module.

The model having been created, it was possible to calculate the **energy needs** of the modules from the measurement sets. IMMS extended the OpenWSN simulation environment, adding a component to calculate the energy consumption. This meant that an effectively practical validation of the consumption calculated was carried out without necessitating lengthy ongoing measurements on a real network.

Optimisation

IMMS made use of **time-slotted radio communication** in order to use the inactive phases of the wireless modules for energy-saving purposes. So that the hardware could be optimally configured in energy terms for these phases, the Institute added functions to the software that would deactivate hardware components not actually in use during a particular phase or put the whole module to sleep, waking it as necessary. This produced a significant reduction in energy needs, with the standby current down to less than 2 µA in the inactive phases.

The major part of the energy is used for sending and receiving data over the broadcasting distance. On one hand, the less often data has to be transferred to the radio network, the better for energy consumption. On the other hand, however, this delays the transfer of messages. To keep within real time restrictions, a suitable compromise was found between energy consumption and delay for the rate of data transfer.

Battery

Batteries with a capacity of 8500 mAh permit operation of the module sensor networks for about one year with the modules in constant use. For testing of the system, this was adequate in the first instance. For the approach to be used later as a commercial product, further optimisation will be necessary. It would above all be possible to switch off the modules when this train is stationary and further to reduce the frequency of radio communication between the modules. These results and further calculation during simulation will have to achieve matching of battery capacity to the maintenance interval. As an alternative it may be possible to apply energy harvesting by the use of accumulators which can be continuously recharged while the train is travelling.

Communication latency

Systemic latency

The data is transferred between modules within signalling distance of each other in the radio network at fixed times, i.e. within slots of time: this time-slotted type of communication which is a source of latency. The latency is dependent on two values. One is the number of hops required, i.e. the signalling distance between neighbouring radio modules along the communication route. The other variable is the pattern of the time window with reference to slot length, number and distribution. Allocation of time windows to hops is random. As radio communication is only allowed in the slots as allocated, a message is held up in its module until the next slot is available. The pattern is repeated in cycles for a set number of slots.

The deeply linear topology that is typical of freight trains means there will be many hops – the individual latencies for the 100 hops in the case of 100 trucks really add up.

Optimisation

By optimising the slot distribution, it proved possible to guarantee that the limits for communication latency would not be exceeded. IMMS composed a pattern of slots (and implemented it in OpenWSN software) which is perfectly adapted to the linear order of the wireless modules in the train and which reallocates the slots each time the trainset is modified. The distribution of the slots over time ensures that the messages hop forward as fast as is possible. There is an example shown in Figure 3.

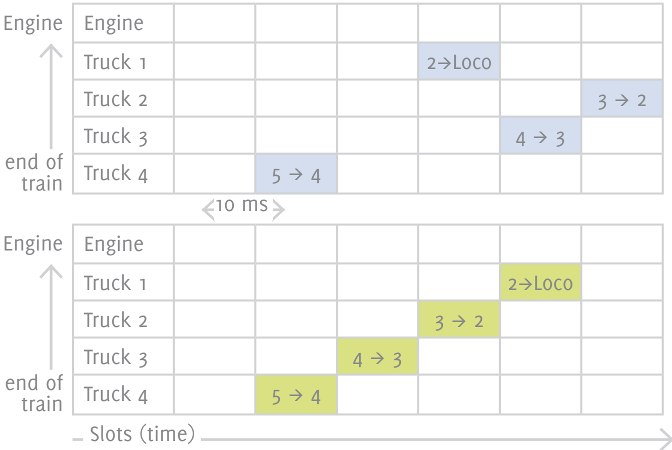

Fig. 3:

Distribution of time slots in a train composed of engine and four trucks – typical (top) and optimised (bottom).

Diagram: IMMS.

The latency typical of message transfer between two neighbouring modules was brought down to a fifth of the original by the optimisation. If a train has 100 trucks, therefore, the maximum transfer time for a message between the last truck and the engine will be about one second, arriving half a second sooner than was at first required.

Demonstrator

IMMS has worked out the principles of acquisition and transfer of sensor data in a wireless network with optimised latency and energy-saving. The individual components thus created were installed in a model train to demonstrate the results that have been obtained. This miniature representation of an actual realtime trainset monitoring system means that these proven principles and methods can be applied in practice almost without further change.

An industrial compact PC made by HARTING (on which Linux has been installed as operating system) is connected up to the demonstrator train with its five trucks and to the sensor network formed by the five wireless modules. The dedicated software developed by IMMS collects the data from the wireless modules and transfers them in customised form to the central control point by cable connection. The software creates enquiries for the wireless modules in appropriately configured messages to send in the reverse direction. The visualisation software that has been developed by the IMMS partner, FUNKWERK, enables the demonstrator to show what the trainset monitoring system may look like in future.

The freight train monitoring system validated in the functioning demonstrator has been for IMMS an important foundation to its definition of design guidelines for a wireless sensor network with optimal latency and energy-saving features. These guidelines are themselves a valuable basis for future work in the wireless sensor network field and a valuable addition to IMMS' areas of competence.

Preparations have been made to combine the system into a prototype that can be tested in real conditions. Currently, IMMS is looking for partners in railway technology. In this search, the project results are to be presented to the TIS, the German association for rail freight innovation.

More on communication solutions at www.imms.de.

All the knowledge gained is of relevance not only for the particular scenario of freight train monitoring but also for other applications where wireless monitoring of distributed objects is required, and is thus transferable.

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More on fast realtime at www.imms.de

On evaluating the new methods, IMMS' industrial partner Melexis was able to identify the problematic points in three circuits in a very short time. Left: Dr. Dirk Nuernbergk (Melexis); right: Georg Gläser (IMMS). Photograph: IMMS.

Motivation: New ways of designing faultless complex systems fast for the fourth industrial revolution

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. System-on-Chip (SoC) technology comprises 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. In the context of Industry 4.0, also known as the fourth Industrial revolution, there is a further imperative: to design yet smarter and thus even more complex systems to meet new demands. Research is focussing 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.

More on ANCONA at www.imms.de.

In anticipation, the ANCONA project partners have been 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 integrated circuits. They will boost innovation potential and give their user a competitive edge. The specific development focus of IMMS has been on design methods which will, among other things, integrate parasitic coupling into system models and enable the coupling phenomena to be efficiently simulated. Three of these methods are presented here.

The IMMS solutions

Why are new methods needed and what is the concept? Top-down design and bottom-up verification – a survey

More on ASIC developments: www.imms.de.

The design of integrated circuits usually begins at the systems level, as shown in Figure 1. It is here that function blocks are combined. Circuits are created within these components that will provide the desired function, amplification for example. And it is after this design stage that the functionality and electrical properties of the blocks are verified by means of simulation. If this stage goes well, a layout is designed to serve as template for the chip manufacturer, with such components as transistors and resistances positioned and linked by metallic connections.

New effects arise from the layout selected for these elements. There may, for example, be crosstalk between neighbouring connections which is caused by parasitics. Such physical effects, quite unrelated to the desired function, mean that the circuit must be verified anew. Usually, the layout has to go through further optimisation stages because of these effects. It is here that the first two methods presented in this article are helpful: parasitic impact analysis and symmetry analysis. Using symmetry analysis, it is possible that optimisation potential will show up even before the layout takes place. Impact analysis is a way of looking at existing layouts to decide on promising sites where improvements could be brought in. These methods thus considerably shorten layout optimisation time.

When correct functionality has been assured, the system can be tested stage by stage in ever larger function groups. If on the large scale there is a need not only for the functions themselves but for monitoring of operating conditions, extremely accurate simulation at a low level of abstraction will usually be necessary, i.e. taking

Implementation | **Verification**

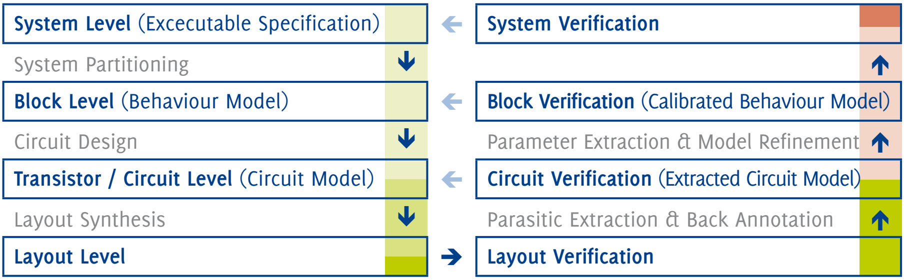


Figure 1: Design and verification levels for ICs as extended by the new approaches: sensitivity analysis, parasitic symmetry extraction, parasitic debugging, model coverage & checker integration, methods of simulation (PTD, FPGA-based) developed by IMMS. Diagram: IMMS.

much time and computation. It is here that the third method comes in: in it, data on permitted operational conditions for individual function blocks is automatically extracted. It is then possible to integrate this data into more abstract models that will speed up simulation and at the same time provide security during subsequent operation later.

Parasitic impact analysis

Diagnosis and manual management of parasitics wearisome to impossible

Parasitic coupling due to the layout can be devastating to the function of a circuit and its electrical properties. This may result in high impact on stability, with other circuit elements disrupted or systematic errors developing which shift the set zero point, leading to offsets and thus to inaccuracy.

See "Impact Rating of Layout Parasitics ...": www.imms.de

IMMS has applied and tested each of the new approaches in the case of specific chip development. In one case, the circuit shown in Figure 2 from the ADMONT project was subjected to parasitic impact analysis. This sampling circuit is used in a highly sensitive image sensor for fluorescence imaging. The accuracy of the circuit block is thus crucial to the chip function and it lies within the target range of <5mV. This value has to be as close as possible to zero. When the circuit was simulated, a negligible offset was revealed (<1mV). However, after layout, simulation with parasitics showed a significantly higher offset (>10mV) which would be excessive for the fluorescence chip.

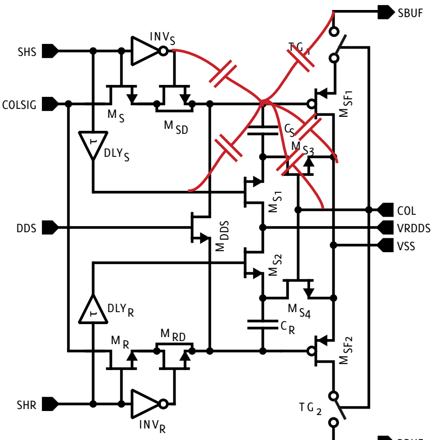


Figure 2:
Sampling circuit in a fluorescence imager from the ADMONT project. Some of the parasitics are marked in red. Diagram: IMMS.

Existing tools reveal the problem but are unable to identify the parasitic elements leading to the error.

It is, of course, physically possible for a designer to modify a circuit affected by parasitics manually and to investigate individual coupling effects. Such elements, however, typically run into the hundreds up to a thousand, which makes the approach rather less than practicable and at the same time requires deep knowledge of the circuit.

A program to find and evaluate critical parasitics automatically

IMMS has created a program that enables these manual modifications to be automated and, at the same time, enables the circuit simulator to be used for evaluation of the modification that has taken place automatically. This is how the algorithm shown in Figure 3 was put into practice: each parasitic element is separated from the circuit in turn and a simulation run is started to determine the electrical properties. The result is a list allocating to each element its influence on the circuit. With the list, identification of the parasitic elements which will have a negative effect on the properties is simple. The number of simulations required is, however, huge: the simulation for evaluation purposes has to take place in respect of every single parasitic element.

To reduce this huge amount of simulation work, the algorithm was further improved. Instead of individual parasitic elements, all electrical couplings emanating from each circuit node can be examined. As there are far fewer nodes than parasitic elements, simulation is then much speedier.

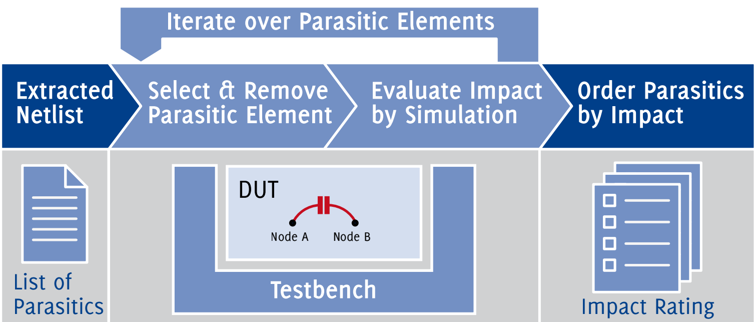


Figure 3:

Impact analysis procedure.

Diagram: IMMS.

For the circuit shown in Figure 2, it was necessary to examine 450 individual couplings but only about 20 nodes. The improvement thus led to simulation effort reduced by a factor of 20. Five critical points were revealed in the space of 10 minutes. The layout of the fluorescence chip was improved, with absolute exactitude.

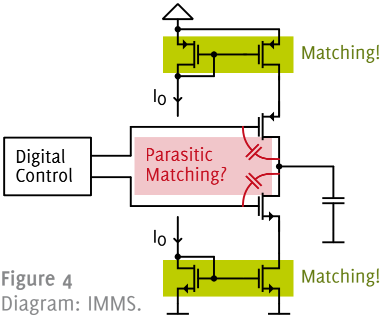
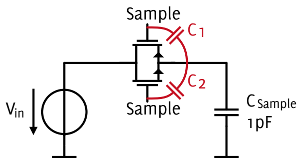


Figure 4
Diagram: IMMS.

◂ It is the state of the art to set symmetry conditions for transistors, for instance in the case of current mirrors (highlighted in green).

For the parasitics (marked in red) there is to date no such method available.



▴ A simple sampling-and-stopping circuit. Parasitic coupling capacitors are marked in red. If they are symmetrical, they eliminate systematic errors.

Symmetry analysis

Symmetry can compensate for errors – also in the case of parasitics

Symmetry is one of nature’s basic concepts and one of technology’s, too, which is also relevant for integrated circuits. Symmetry is exploited particularly at the layout stage to ensure components behave similarly in the presence of process variation. One instance is always to lay out current mirror circuits in symmetrical patterns. These symmetry conditions can be set in the circuit diagram even before layout, as shown in Figure 4.

See ”Parasitic Symmetry at a Glance ...“: www.imms.de

However, there has so far been no way of applying such conditions to parasitic elements, which may well cause systematic deviation in, for instance, sampling-and-hold circuits. One of these is shown in Figure 4. If the coupling currents of the circuit signals marked in red are equal to the output signal, the couplings compensate for each other and there will be no systematic error.

New acceptance regions concept means symmetry extraction possible for parasitic elements

A method and also a tool prototype have been developed at IMMS from this principle within the ANCONA project. With the method it is possible to identify later symmetry conditions for parasitics in the layout before the actual layout takes place. The basis is the idea of acceptance regions, as shown in Figure 5. An acceptance region is a section of an area of parameters in which a particular circuit will work without error, i.e. within the specified tolerances.

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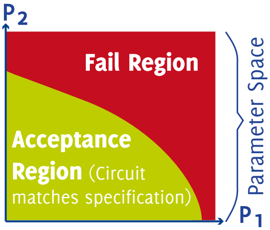
Figure 5: Acceptance region concept. Diagram: IMMS.



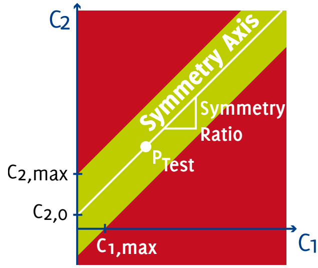


Figure 6:

Shape of acceptance region for symmetry condition.

Diagram: IMMS.

Acceptance regions – example

For example, in the case of the fluorescence chip described above, the specification is as follows: the output voltage is permitted to vary from the input voltage at the moment of sampling by only 5mV. If the parameters of parasitics C_1 and C_2 now vary, a picture will emerge as in Figure 6: the symmetry condition produces an acceptance corridor which lies within the specified area. Within this corridor, the capacity can vary without affecting the behaviour of the circuit. This shape of acceptance region is typical of symmetry conditions. It can be represented by means of three values: two of these are the two intersections with the axes C_1, max and $C_{\{2, max\}}$, the third is the slope of the axis of symmetry (the relation between the capacities).

Example of symmetry conditions

If the acceptance regions for all possible parasitics are investigated, symmetry conditions can be identified. To do so requires determining the maximum values of the capacities which can be tolerated, i.e. the intersections between the acceptance regions and the coordinate axes. To test whether a symmetry condition is contained in the overall parameter area under observation, a point along the axis of symmetry is selected. If the circuit behaviour is correct for this combination of parameters, i.e. if the point is found to lie in the "green region", a condition of symmetry has been shown.

Following this method does, however, require very many simulation runs. Their number can be greatly reduced by additional heuristic and plausibility tests. In collaboration with the ADMONT project, a circuit from an imager was investigated (see Figure 2). The analysis took six hours of simulation and produced more than 200 conditions of symmetry. The knowledge gained brought deeper understanding of the parasitics arising and can now be used for optimisation of the layout.

Model safeguard unit (MSU) – the end of false verification positives when operating conditions are used

False positives in verification mean wearisome simulation and manual correction

”The verification of a system tells you only as much as the models you use.“ Up to now there has been the possibility that positive verification of a design with purely functional models might turn out to be false and require validation by additional costly simulations.

This state of affairs is shown in Figure 7: if a model is run as in this case with too low a supply voltage, i.e. in a region in which the circuit would not function in practice, and yet produces a correct result, the verification is not reliable. An example of the situation is passive RFID tags which obtain their energy from the electromagnetic field, thus being subject to operating conditions which constantly vary.

To avoid this, it has been necessary so far to enter additional test conditions into the model manually or to carry out additional, time-consuming simulations.

There has to date been no way of generating the test conditions automatically for analog/mixed signal systems and entering them into existing models. For this reason IMMS made use of the concept of acceptance regions, working with the section of the parameter area in which the circuit functions according to specification.

See ”There is a limit to everything ...“: www.imms.de

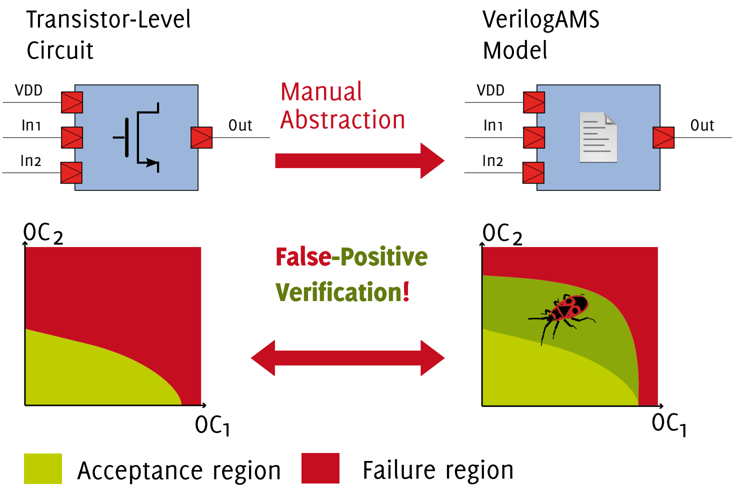


Figure 7:

Running a model in a region in which the circuit does not function can lead to falsely positive verification results.

Diagram: IMMS.

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How do the test conditions and acceptance regions get into the model automatically?

Quality before quantity

For the acceptance region to be integrated into a model, a suitable method of representation must first be found that can be visually represented in the IC design environment. As in industry, the Cadence AMS designer system is used. With this program, for instance, VerilogAMS models can be simulated. The decision as to whether the current environmental conditions are within or outside the acceptance region is a matter of classification. Because of the high flexibility, the choice of classifier falls on an SVM (support vector machine), which is a mathematical classification procedure. A method of automatically representing the classifiers in VerilogAMS models has been developed at IMMS.

Automatically generated test condition observes and acts

As explained above, an SVM is used to represent the acceptance region. This classifier forms the core of an automatically generated test condition such as is shown in Figure 8. This unit contains not only the classifier. One other item is observer modules for purposes of monitoring the environment within the simulation. Another item is actuator modules for purposes of reacting to departure from the applicable operating area, for instance if a warning message is given or the system behaviour changes.

See "*Knowing your A/MS System's Limit ...*": www.imms.de

Now, thanks to a tool created by IMMS, the generation and integration of this test condition can be fully automated. New blocks are entered into the existing model, connecting leads are disconnected and connected anew. The process is shown in Figure 9. After the acceptance region for the circuit has been established, the classifier is trained and then transferred into VerilogAMS. This process entails combining the structure shown above, with its observer sensors and actuators, and integrating it into the existing model.

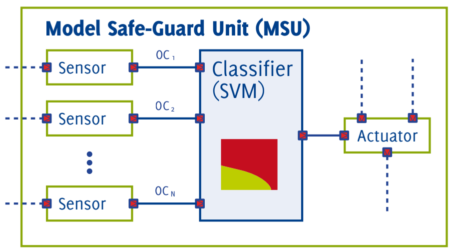

Figure 8:

Structure of the Model Safe-Guard Unit. Diagram: IMMS.

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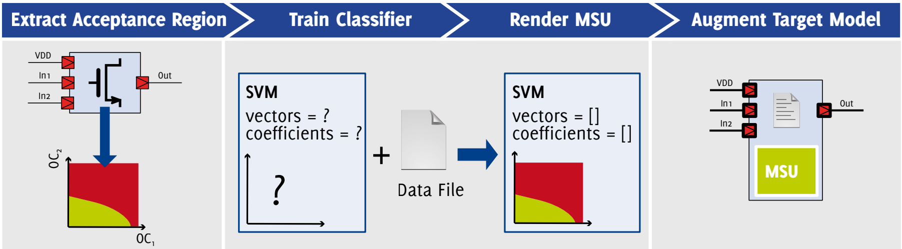


Figure 9: Creation of the MSU. Diagram: IMMS.

Passive RFID chip as example – tool cuts simulation time

Among the things IMMS develops in the ADMONT project are passive RFID frontends. It is essential to test these with reference to varying operating conditions because the power supply of the system components is constantly changing with changes in the field situation. The demodulator block from Figure 10 is an example. It obtains its data signal from the magnetic field in order to achieve communication with the tag.

During verification it became clear that simple functional modelling without reference to the environmental conditions is inadequate. There is a representation of this in Figure 11, with supply voltage VDD, equivalent value VDC and amplitude VAC of the input signal: the circuit will function properly in the green area but there will be interruptions to function in the red areas. On comparing the acceptance regions for the model (b) and the circuit (a), it will be seen that the model functions correctly even at VDD=0, i.e. with no voltage supply at all.

Other RFID solutions in the ADMONT specialist article.

This can result in a falsely positive verification. So a test condition was created following the method described above and integrated into the system. The whole process took approx. 10 hours and produced an extended model of the demodulator which it is possible to simulate 100 times faster than the circuit can be.

Comparing the acceptance regions from Figure 11 (a) with the extended model (c) reveals that the acceptance regions match. Using a procedure also developed in the context of ANCONA, it has been proven that the risk of false positives in verification is almost completely excluded by this means.

More on ASIC developments: www.imms.de.

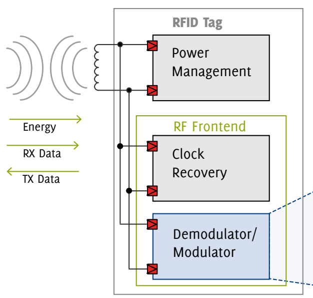
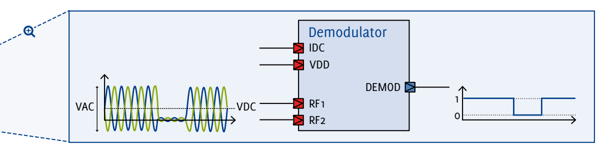
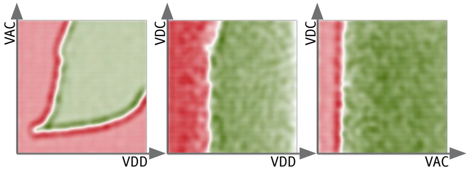


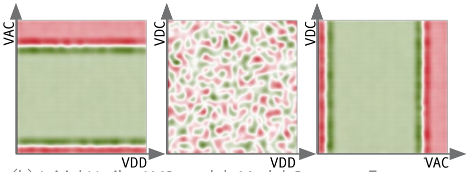
Figure 10:

Sample system: the demodulator of a passive RFID tag. Diagram: IMMS.

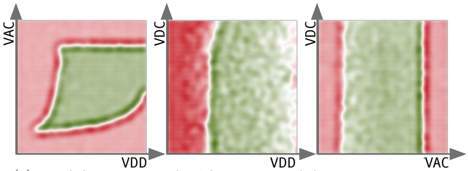




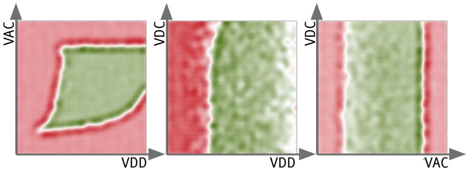
(a) Transistor Level implementation



(b) Initial VerilogAMS model. Model Coverage $\Gamma_B \approx 0.75$.



(c) Model augmented with MSU. Model Coverage $\Gamma_B \approx 0.98$.



(d) Model augmented with MSU, MSU, safety-margin 50 mV. Model Coverage $\Gamma_B \approx 1$.

Figure 11: comparison of the circuit and model acceptance regions with and without MSU. Diagram: IMMS.

Future prospects

At the "14th International Conference on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design" (SMACD 2017) in June 2017, IMMS and its research partners were named competition runner-up for their contribution,"Automated Generation of System-Level AMS Operating Condition Checks: Your Model's Insurance Policy". Before that, IMMS received two "Best Paper" awards at international conferences in 2016 and 2015: FDL (Forum on Specification & Design Languages). And by the end of 2017, the results from ANCONA had been published in sixteen papers, among which eight peer-reviewed publications, nine lectures, four specialist posters and two book chapters.

For Fig. 11a see "Comparing Apples and Oranges: ...": www.imms.de

IMMS contributed crucial building blocks to the project in support of the aims: to ensure the reliability of the design of today's microelectronic systems. IMMS incorporated the new-style verification method into its research projects as an enhancement of the quality of designs made in those projects. Knowledge gained from this has been fed back into optimisation of the new method. IMMS has so far used the new methods for three chip developments in the ADMONT* and RoMulus* projects. Melexis, a long-standing industrial partner, was also able to identify the problem areas of three circuits in a very short time. It is intended that all the experience gained will be employed in the further development of the method in coming EDA projects.

More on ANCONA at www.imms.de.

Contact person: Georg Gläser, M.A., georg.glaeser@imms.de

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RESEARCH SUBJECT

INTEGRAED SENSOR SYSTEMS FOR BIOLOGICAL ANALYSIS AND MEDICAL TECHNOLOGY

Test setup for a prototype of a microelectronic-based system which will enable doctors to perform diagnostic tests for cervical cancer quickly and reliably on site in the future. IMMS developed the prototype in the MIMOSE* project on the foundation of the DNA-based detection principle for unequivocal diagnosis which was created by the partner oncgnostics GmbH. Photograph: IMMS.

Research subject "Integrated sensor systems for biological analysis and medical technology"

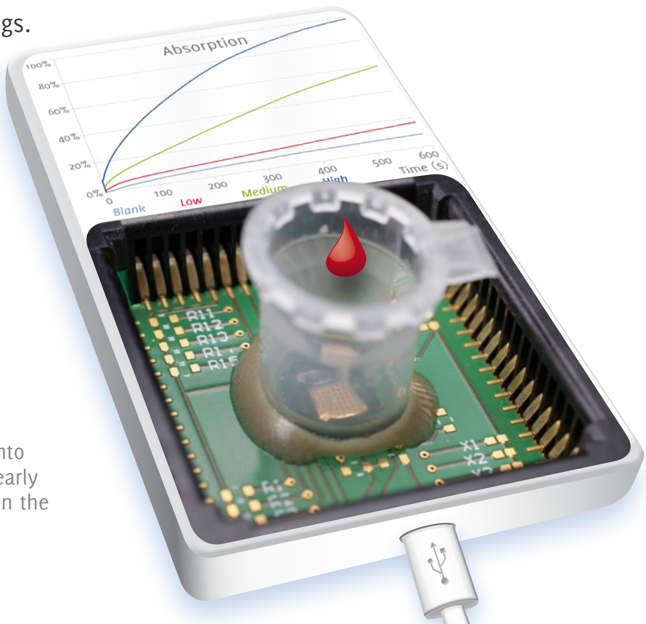
Increasing life expectancy in our societies lead to a rise of serious diseases such as cancer, cardiovascular disorders and dementia and to a growth of related expenditures for diagnostic analysis and therapy. Our research on microelectronic biosensor systems for medical diagnostics and personalised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

Photograph: IMMS.

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.

Projects in this field at www.imms.de.

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.



Concept sketch of a mobile point-of-care diagnosis system.

The module containing PCB, ASIC and reservoir has already been incorporated into the experimental setup for early cancer diagnosis described in the INSPECT report.

Diagram/photograph: IMMS.

More on point-of-care diagnostics at www.imms.de.

Highlights of 2017 in our research on integrated sensor systems for biological analysis and medical technology

End of MIMOSE* project: electronics for the early diagnosis of cervical cancer

The MIMOSE project ended in 2017. In it, IMMS brought to the prototype stage a system with a measurement concept using microelectronics which will enable doctors in the future to carry out conclusive point-of-care diagnostic tests on the basis of DNA. The DNA-based detection method is a principle developed by oncgnostics GmbH that makes screening for early cervical cancer unequivocal.

MIMOSE at www.imms.de.

Current screening inconclusive

In Germany, more than 200.000 women a year receive a laboratory report on their smear test which suggests the presence of cervical cancer but is not conclusive.

The reason is that the Pap test, in which smears are investigated under the microscope for conspicuous cells, is very much dependent on the experience of the particular laboratories and, consequently, very subjective. The cytological disparities seen largely indicate infection or benign tissue changes which will heal naturally. To clear up the cancer question, tests are carried out for human papillomaviruses, as these are almost always precursors of cervical cancer. Only if this further laboratory testing comes out negative, can a patient be certain that she does not have cervical cancer despite the finding of anomalous cells.

Usually, however, the virus test comes out positive, and very frequently tissue will be removed from the cervix after this. Yet many of these operations are unnecessary, for most of the viral infections will heal off themselves without being followed by cancer. On the contrary, the operations to remove tissue may well have serious consequences for women wishing to conceive. In the operation the cervix is shortened, increasing the risk of stillbirth or prematurity.

Conclusive diagnosis through laboratory investigation based on DNA

In GynTect®, IMMS' business partner oncgnostics GmbH has developed a simple and reliable proof of the presence of cervical cancer. This test makes use of the fact that certain DNA marker genes undergo a chemical change, methylation, in cancer cells. Methylation of the specialised DNA marker genes validated by the oncgnostics com-

Test set-up for the prototype of a micro-electronic-based system for the early detection of cervical cancer developed at IMMS, which will enable doctors to carry out conclusive point-of-care diagnostic tests. The basis was the DNA-based detection principle developed by the partner oncgnostics GmbH, which provides clear results. Photo: IMMS.

pany can be clearly detected in diagnostic labs from smear tests if these are carried out appropriately. Methylation markers are not present in healthy tissue. This test obviates unnecessary operations.

Smoother procedure and point-of-care diagnosis with microelectronics and a mobile testing system

On the basis of electronic sensors, IMMS has developed new detection principles that are capable of innovatory, exact recognition of DNA marker genes at high resolution. The automated diagnostic platform ensures high-quality, highly reliable cancer detection by using a dual microelectronic recognition scheme to detect any methylation of markers without fail.

Working with this platform, IMMS has developed, manufactured and tested an actual prototype diagnostic device. The work included specification, development, verification, manufacture, further construction and connection plus testing of two microelectronic systems for two different diagnostic procedures. With the prototype, IMMS has proved the suitability of the microelectronic system for revealing methylation of markers in the cervical cancer case. The diagnostic apparatus has already been adapted to bio-analytic requirements and the two electronic measurement systems have been fully developed, fabricated and tested. Within the project, another success was that DNA collected on the probes was immobilised on IMMS microelectronic systems, with proof of hybridisation. From the very first, IMMS geared its work in this field towards developing a user-friendly biocompatible system design which can serve in the future as the foundation for the development of a diagnosis system capable of easy use in doctors' consulting rooms.

More on ASIC developments: www.imms.de.

More on system integration at www.imms.de.

More tests planned in internal follow-up project

The prototype developed as part of MIMOSE has become a vital foundation for mobile microelectronic-based diagnostic equipment in the early stages of cancer. In conjunction with oncgnostics GmbH, IMMS is continuing comprehensive testing with the prototype even after the closure of the development stage in MIMOSE. These test series are intended not only to be the basis of further commercial development but also to help IMMS draw conclusions on further electronics applicable in bio-analytics. A number of technical solutions developed within MIMOSE are currently being analysed for their commercial potential and possible patenting. Enough said here: publications will follow.

At MEDICA: microelectronics for early cancer diagnosis, treatment of blindness and analysis of liquids

At the MEDICA trade fair in Düsseldorf in November, 2017, IMMS presented three innovations: a point-of-care test system using microelectronics to diagnose cancer at an early stage, a microelectronic means of analysing aqueous solutions using passive RFID sensors, and a bionic system to treat blindness. Showing its functional samples and prototypes, the Institute was able to give hands-on experience of the current state of its work in the bioanalytics field. It also presented chips developed for medical technology that are already in use in the epi-retinal systems made by its business partner, Pixium Vision, at the clinical study stage for patients who have gone blind.

Current events at www.imms.de.

As a member of the network DiagnostikNet Berlin-Brandenburg, IMMS exhibited at the joint booth at the MEDICA 2017 trade fair microelectronics for the early detection of cancer, the treatment of blindness and the analysis of fluids.

Photograph: IMMS.

Point-of-care rapid testing for prostate and colone cancer with microelectronics

On its stand at MEDICA, IMMS gave live demonstrations of the principles behind quantitative early diagnosis of cancer using its functional sample. IMMS is in process of developing the microelectronics that will recognise prostate and colon cancer at a very early stage: tiny antigen concentrations (less than 1 ng per ml) are measured in direct contact with the sample. The aim is that the doctor caring for the patient will have rapid, easy-to-manage tests that deliver the same accuracy as time-consuming laboratory investigation using complex equipment. As quickly and cheaply as a standard stick test. There is a full scientific report on the current work in this annual report, titled INSPECT.

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Quantities in aqueous solutions signaled by battery-free RFID sensor chip

Another prototype presented at MEDICA was used in live demonstrations to show how the temperature data for aqueous solutions could be measured using passive RFID sensors that are without any power supply, followed by RFID readout unit processing. This readout unit generates a magnetic field which is sufficient to supply a passive RFID chip with enough power to pass through container and liquid for a distance of up to 4 cm and to acquire and transmit the measured data. The principle shown at the trade fair in respect of temperature using battery-free RFID sensors is currently being transferred at IMMS to other measured values and is the subject of the specialist article on ADMONT.

Go to the INSPECT article.

Go to the ADMONT article.

IRIS®II – bionic system to treat blindness: the microelectronics for an implant into the eye

In the IRIS®II system created by IMMS' partner, PIXIUM Vision, and presented at MEDICA, there is an implantable, biocompatible, microelectronic chip developed by IMMS for PIXIUM Vision's epi-retinal system. The chip forms part of an optical implant enabling people to regain partial vision who have lost their sight through retinal degeneration but still possess an intact optic nerve. They wear spectacles with an integrated camera which will photograph the environment. The digital image data is transferred to the retinal implant through the pupil.

The IMMS chip translates the optical information into an electronic data stream, which is then sent to a device called a retina stimulator whose task is to stimulate the optic nerve so that a visual image is formed in the brain.

After 30 years of blindness, the first Spanish patient in a clinical trial can locate objects with IRIS®II, the bionic system for the treatment of blindness.

The IMMS chip is in the retinal implant.

Photograph: Fundación IMO.

Clinical studies are running in Europe in which patients with IRIS®II implants take part in rehabilitation programmes teaching them to interpret this new form of visual image. The first therapeutic success was reported from Spain in 2017. IMMS at MEDICA demonstrated the systems with which the patients are equipped and showed examples from the clinical studies on video, with reports from patients.

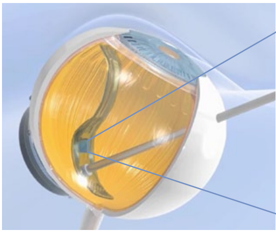
Microelectronics under challenge

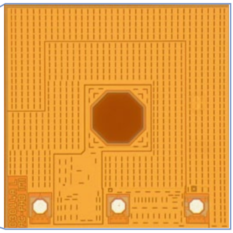
"Such a retinal implant is a big challenge from an engineering point of view, not only with regards to miniaturisation and functionality," says Khalid Ishaque, CEO at Pixium Vision as he looks back on 15 years of R and D. "Imagine wanting to have a working TV underwater in the Mediterranean Sea, which is warm, moving and salty. It's kind of similar challenge for such a microelectronic implant in your eye." This electronic implant must be so flexibly configured that it will continue to function flawlessly when the eye is rolled. And not only that, the electronics have to work with minimum energy consumption and within non-critical thermal safety limits. Inside the human body, circuits cannot be supplied with direct current for their energy supply as would otherwise be customary. It was therefore necessary to create a chip that was supplied by alternative current.

Details and videos on IRIS®II: www.imms.de.

IMMS chip converts images into signals for the undamaged optic nerve

The infrared receiver chip developed at IMMS is inserted into the eye and converts the data received via the optical interface into an electric signal, passing this on to the stimulator chip. IMMS have created and tested the elements crucial to these functions: the photodiode, the control circuit detecting signals, and the output driver, also implementing circuit schemes which achieve minimum energy consump-





Retinal implant of the IRIS®II system (left). The chip of IMMS (right) with photodiode in the center translates the optical information into an electronic data stream. This is transmitted to a retinal stimulator that excites the optic nerve. Diagram (left): Pixium Vision. Chip photo (right): IMMS.

tion and minimum heat development alongside constant standby readiness. These circuits consume less than 120 µA.

The chip as designed by IMMS, being in the human body, has alternative current as its power supply. Into it, a rectifier is integrated which converts AC to DC in a hermetically sealed circuit. This means that the supply current cannot be analysed by standard measurements and IMMS has developed a new method. The value for the supply current is established using an inductive current sensor.

More on ASIC developments: www.imms.de.

"IMMS delivered a vital contribution to our goal of restoring partial perception to people with vision loss from retinitis pigmentosa. The chip made by IMMS is the fundamental part of the gateway between the real world to the eye through the optic nerve and the brain of the patient," sayd Khalid Ishaque, CEO of Pixium. "But for him, after surgery the hard work starts – which involves retraining the brain." Pixium Vision is cooperating with experts in many nations and many disciplines who come from neuroscience, physics, optics, mathematics, microsurgery, ophthalmic surgery and fields of expertise on visual defects. "This global ecosystem of partners is critical to the success on this journey, which was not so long ago considered impossible."

Details and videos on IRIS®II: www.imms.de.

INSPECT – Microelectronics to diagnose cancer: initial work on immobilising bio-markers

Early experiments with a mobile testing system to contribute to integrated systems of personalised cancer diagnosis at an early stage. Photograph: IMMS.

Objectives and overview

The goal: rapid, early, precise diagnostic tests for cancer

There are certain types of cancer for which the patient's doctor can test rapidly on the spot, avoiding the need for costly, time-consuming lab tests. The common rapid diagnostic tests are qualitative rather than quantitative. They give a "yes" or "no" answer in the form of a coloured line on a paper strip which is either present or absent. For the future, it is hoped that rapid microelectronic tests will become possible so that doctors can get precise diagnostic information comperable to the results of extensive analysis of samples using complex laboratory equipment, but with the ease of test strips.

Details and video for the INSPECT project: www.imms.de.

There is now an intention to use microelectronics to recognise prostate and colon cancer at a very early stage by measuring tiny antigen concentrations (less than 1 ng per ml) by bringing the chip into direct contact with samples from the patient. For prostate cancer in particular, this method will be a great advance on today's point-of-care testing procedures. Although the presence of PSA (prostate-specific antigen) may be an indicator of cancer, it is constantly being produced in the male body. As men age, the concentration of PSA in their blood rises from around 2.5 nanograms (millionths of a gram) per millilitre to around 6.5 ng/ml. However, it can vary independently of a man's age, inflammation, mechanical irritation or cancer being the possible reasons. If a patient's PSA concentration could be measured at regular intervals, reliable early diagnosis and thus early treatment would be possible.

Staged preliminary investigation with chip technology and a mobile test system

Stage 1: Recognition of known particle concentrations in sample fluids
In the INSPECT project, together with its business partner Senova, IMMS has developed a functioning prototype system for microelectronic-based testing to help early diagnosis of prostate and colon cancer. The system serves to investigate significant parameters for cancer screening and to provide exact data on luminous intensity and particle concentation in patient samples. At the heart of the prototype is a chip previously developed by IMMS for proof of the existence of infections. In the present instance, this chip has been employed in a feasibility study with regard to the quantitative cancer screening goals and then to show that its integrated photodiodes are capable of revealing as expected the different levels of brightness caused by enzyme reactions in samples with known particle concentrations.

See article on INSPECT at www.imms.de.

Stage 2: Detection of gold particle markers and determination of detection limit
On the basis of Senova's knowhow on immunological assays in the diagnosis of carcinomas and on linking electronic functions with biochemistry, the partners were able to use the prototype described above to show that tiny quantities of gold nanoparticles can be revealed by digital optical methods. It is common for these particles to be employed in diagnostic procedures to render bio-markers visible and thus optically detectable. Using a spectrophotometer as customary in laboratories, the concentrations of gold particles revealed by the prototype test system at the minimum measurable optical density of 0.009 Bel were compared with those from experiments on samples with like concentrations.

More on ASIC development at www.imms.de.

It is on the basis of this work and other investigations that IMMS has laid out the ASIC (application-specific integrated circuit) to be applied specifically to cancer screening. In particular, close attention has to be paid to signal processing where there is only a tiny differential between signals and to efficient noise suppression.

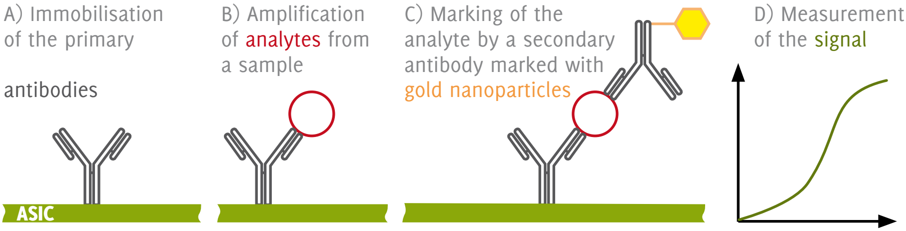


Figure 1: Basic principle, quantitative detection of PSA or haemoglobin analytes. Diagram: Senova/IMMS.

The IMMS solution in detail

Simple-as-a-strip micro-processor system that measures exactly

Gold nanoparticles rendering antibody-antigen complexes visible

Biologically, the new system of testing works on the same principle as paper strips, in that the interaction between antibody and antigen should enable detection of analytes in patient samples (prostate-specific antigen (PSA) in the case of prostate cancer and haemoglobin in the case of colon cancer). As shown in Figure 1(A), the primary antibodies are first fixed vertically on the surface of a micro-electronic chip by biochemical means. If any of the suspected PSA or haemoglobin antigens are contained in the fluid, sample fluid applied to the chip forms invisible antibody-antigen complexes (B). It takes a second step to make these visible: secondary antibodies with a marker are added, which dock onto the analytes of the antibody-antigen complexes (C). Possible markers are nanoparticles of gold to make the sample solution cloudy by absorbing light. Then the cloudy solution with the secondary antibodies which are not bound to the surface is rinsed off. The secondary antibodies which have been retained by the primary ones and marked with the gold cause a modification of optical density which can be detected by the ASIC and evaluated (D).

Chip to measure brightness variations caused by a single nanogram of antigen per millilitre

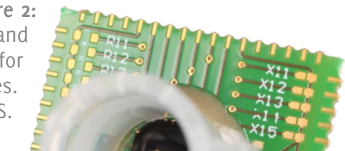
The luminous intensity is measured before and after the reaction and the degree of attenuation determined. The logarithmic ratio between the two measured values gives the alteration in the optical density (OD) in Bel. If cancer is to be diagnosed at a very early stage, the chip must be capable of recognising concentrations of antigens in the range of one nanogram per cubic centimetre. At this range, the variations in luminous intensity will be very weak in dimensions between 0.01 Bel and 1 Bel (1 decibel is 0.1 Bel).

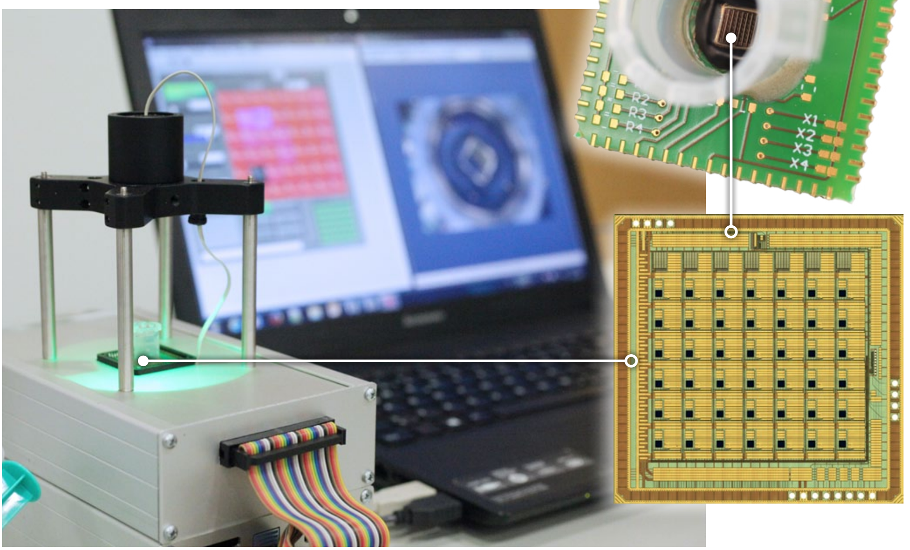
Experimental chip beats the target in recognising immobilised nanoparticles of gold

So that the principles of immobilisation and clouding described above could be represented on the immediate surface of the sensor, experiments were first carried out, using the ASIC which already existed, with nanoparticles of gold but without the antibody-antigen complexes. The chip is still quite large, being for research purposes. It was intended at first for detecting infectious illness, i.e. for rather different conditions. It contains a 6 x 7 matrix of photodiodes (Figure 2) and was developed for parallel detection of various pathogens by measuring how luminous intensity varied. The optical principle behind the signal conversion for this research chip is now to be transferred for use in cancer diagnosis and incorporated into the layout of an ASIC designed anew for the new requirements.

Five sets of the equipment seen in Figure 2, each fitted with one of the research chips, were investigated. On each of these five ASICs 100 microlitres (µl) of solution with a certain defined quantity of particles of gold, diameter 60 nanometres (nm), was placed and dried at 37°C with a maximum of 7 % humidity. In the five successive reservoirs, the number of particles was doubled from solution to solution.

Figure 2:
Measurement setup (left) with liquid reservoir (top right) and ASIC (bottom right) equipped with a 6 x 7 photodiode matrix for preliminary investigations with gold nanoparticles.
Photographs: IMMS.





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Article on this research chip: www.imms.de.

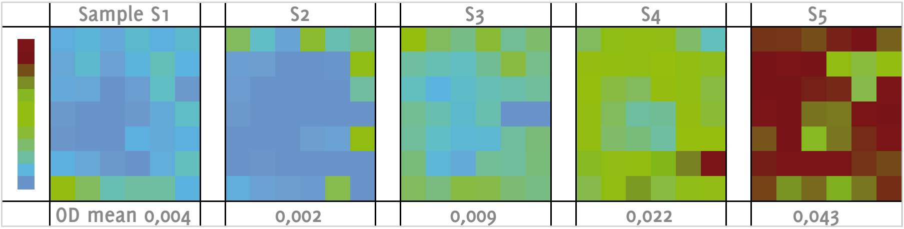

Figure 3: Results obtained after the drying process using five ASICs each with a 6 x 7 photodiode matrix for solutions S1 to S5 containing nanoparticles of gold: blue marks the lowest, green the mean and red the maximum value for optical density (OD, in Bel). The "OD mean" values shown are the values for each ASIC for optical density. Diagram: IMMS.

This was confirmed by contactless optical comparative measurement using a commercially available spectrophotometer typical of bioanalytical laboratories and able to show specific quantities of gold nanoparticles.

The results shown in Figure 3 from the five experimental chips in direct contact with sample solutions show on the one hand that the optical density increases with stronger concentrations of gold nanoparticles, blue representing the lowest, green the mean and red the maximum optical density. The grid in each case shows the 6 x 7 photodiode array on the chip. On the other hand, the distribution of the measured values across the grid makes it clear that the nanoparticles of gold in each sample have during drying process spread more or less irregularly over the sensor surface, as at this stage of the experiment no fixed antibodies have yet been used for purposes of holding the gold particles steady on the surface of the chip. The possibility cannot, therefore, be excluded that gold particles have collected during drying at spots which are not visible to the diodes, for instance on the insides of the reservoir.

The measurements taken on the five experimental chips do reveal that the number of particles per sample on them doubles from sample to sample. It was possible to show that there were significant distinctions between the quantities of particles dried from samples 3, 4 and 5 and actually adherent on the chips as the double concentrations of particles in the solutions coincide with the increasing OD mean figures shown in the lower part of Figure 3 for apparatus 3, 4 and 5. In the case of apparatus 1 and 2, the very low optical density of the solution prohibits any reliable statement because the irregular distribution of the particles has caused most of the measured values to fall close to the noise limit.

The experiment thus served to show a detection boundary at OD 0.009 Bel, as can be seen in the lower section of the S3 graphic in Figure 3. The specified minimum value for optical density difference of 0.01 Bel was thus fully achieved.

Conclusions and Outlook

The experiments described with known quantities of dried nanoparticles of gold in 5 sets of electronic apparatus have shown that the system is in principle suitable for optical measurement where there are immobilised, marked antibody-antigen complexes. The measurements taken by the electronic apparatus are in the optical density target range. In subsequence analyses, the intention is to subject the optical density figures so far obtained using the research chips and the spectrophotometer to quantitative comparison in view of the varying measurement procedures and the irregular particle distribution arising during the drying process which is noted above. In addition, Senova has been using the current chip for further tests with chip surfaces that have been provided with biological functionality and patient samples.

In the course of 2017, it was possible to specify an ASIC on this basis which is smaller, more exact, less affected by noise and better tailored to the application, while at the same time being less costly. In contrast to the original test chip, the INSPECT ASIC will contain a digital element which can preprocess the values registered by analogue means. This will simplify the ensuing signal processing and permit standardised output to data processing systems. There is a further benefit in that, the digitalised signals from the measurement system are less vulnerable to external disturbance.

More on ASIC development at www.imms.de.

More on test and characterisation at www.imms.de.

Details and video for the INSPECT project: www.imms.de.

Contact person: Alexander Hofmann, M.Sc., alexander.hofmann@imms.de

EFRE
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EUROPEAN UNION

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ADMONT –

Battery-less RFID sensor chip transmits measurement data from aqueous solutions

With the passive RFID sensor chip developed at IMMS, it is possible to signal data measurements from aqueous solutions to NFC-enabled devices such as smartphones. One example of use is cell culture monitoring. Photograph: IMMS.

Objectives and overview: Monitoring of cell cultures, microbes and viruses

The growth of cells, viruses and microbes like bacteria or fungi which are being cultured is dependent not only on the nutrients but also on details of the ambient humidity and temperature and pH value of the medium. Lab investigations and sample cultivation stand or fall by the maintenance of constant conditions, particularly temperatures, during experiments. Unfortunately, this is not always possible.

Why are cells, microbes and viruses cultured and under what conditions?

Cell cultures are used not only for pure research into molecular and cellular processes or for diagnostics. They may be needed, among other things, for new pharmaceuticals where the metabolic processes in bacterial growth and the effect, for instance of antibiotics, are being investigated. Human cell cultures can be used in analysing the side effects of new substances (in cosmetics or domestic chemicals) so that animal experiments are cut significantly. The procedure is to take cells from tissue out of the organism and cultivate and test them under sterile, continuously standardised conditions in vitro. If mammalian cells, for instance, are to be cultured and tested, the pH value must be between 7.2 and 7.4, the humidity between 96% and 98% and the temperature kept constant between 37°C and 37.5°C. Depending on the organism, the temperature will be 21°C to 28 °C for soil-dwellers and 4°C to 10°C for sea-dwellers during culture. The conditions to be maintained in investigating cultured microbes and viruses will be similar.

There are bio-technological applications which are for the investigation of such things as thermophile bacteria at temperatures up to and above 100°C. An instance is the attempt to obtain thermostable enzymes for soap and detergent additives. Here again, the strict temperature limits may not be exceeded at any stage of the culture or analysis.

Sensors to monitor fluctuating conditions for samples in the incubator

The chambers used in culturing samples can be accurately regulated up to +100°C and will maintain constant temperatures by circulating the air or employing a water-filled lagging. It must be said, however, that this works well only if the incubators are never or seldom opened. It is often necessary to introduce substances into samples during the sort of serial investigations, e.g. applied to pharmaceuticals, which will mean variations of temperature are also introduced and these may, depending on the culture, sabotage test results.

A possible solution is to make additional measurements enabling critical parameters (temperature, for instance) to be sensed directly in the sample so that the entire series of tests is under continuous, undisturbed quality control. For this, sensors are necessary which will detect these values in the target range flexibly, simply and sufficiently accurately, causing no cross-contamination and no time delay; and using the lab equipment already present.

IMMS' passive RFID sensor chip sends temperature measurements from aqueous solutions

IMMS has developed an RFID (Radio Frequency Identification) sensor chip which is not reliant on an outside power supply. Placed in aqueous solutions, it will measure the temperature so that the quantities are captured by an RFID readout unit and then processed. The energy-efficient chip which has been created by IMMS captures and digitises the relevant quantities using electrical power of only 3.5 microwatts. Theoretically, this means a comparable battery-assisted sensor will operate without interruption for at least a 10-year period from a mignon battery of 1000 mAh typical capacity. However, no battery is necessary in the case of such low power take-up. A

More on ASIC development at www.imms.de.

readout unit generates a magnetic field which is strong enough to supply the passive RFID chip with sufficient power, so that sensor data is captured and transmitted through both container and liquid for a distance of up to 4 cm.

Accuracy and efficiency of both energy and money use are here combined. The new digital temperature sensor employed in the RFID sensor chip is capable of a wide measuring range, from 0°C to 125°C, maintaining absolute accuracy of ±0.4°C across the whole system. To keep costs to a minimum, IMMS has used conventional established CMOS technologies and developed a single-chip solution with an integrated sensor and embedded electronic signal processing. As a result, the only additional component requiring connection to the chip is the RFID antenna. Direct contact with the sampled cultures remains secure because bio-compatible materials are used.

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Currently, the principles put into practice for temperature measurements using a passive RFID sensor are being applied to further varieties of quantity by IMMS. Among these will be pH value, humidity and dissolved oxygen. All will then be possible to monitor when analysing cell cultures, microbes and viruses. Even beyond these bio-analysis possibilities, the development is promising for many and varied other applications. One could be the capturing of relevant parameters affecting industrial manufacture by means of passive RFID sensors, e.g. the details of cooling lubricants. There is the additional advantage that NFC-enabled end devices can be employed as power source and readout unit. Work is therefore going ahead on a demonstrator app for the use of the RFID chip in conjunction with Android-based smartphones.

More on ASIC development at www.imms.de.

Figure 1: RFID system. IMMS developed the RFID tag. Graphic: IMMS.

The IMMS solution in detail

RFID sensors not only to identify but also to measure and signal quantitative data

RFID enables electronic systems to identify objects automatically without any contact and to capture metadata relating to them. Inside an RFID tag which is attached to an object for identification purposes, there is a tiny chip connected to an antenna. The RFID readout device communicates with the tag by magnetic or electromagnetic field. Figure 1 shows the circuit of an RFID system in schematic form.

RFID is not only used to identify an object but can also be used to read and write data onto the radio tag using the RFID readout device. This particular characteristic has a great advantage over conventional barcodes, which do not permit the data to be altered after printing. There are yet more valuable functions in sensor-capable radio tags. These sensor RFID tags contain not only the ”identify“, ”read“ and ”write“ functions but also sensors which can at the same time be used to monitor physical parameters such as temperature.

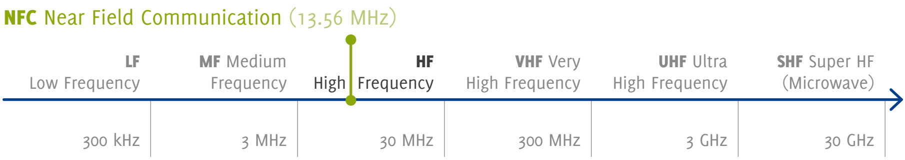
Passive RFID sensors need no batteries; NFC will mean a wide range of applications

RFID technology works over more than one frequency range: from low frequency up to high and ultra high and even microwaves, as shown in Figure 2. The scenario which is the focus of ADMONT and the idea of transfer to industrial use means that IMMS is concentrating on developing RFID temperature sensor tags in the HF range at 13.56 MHz, because in this range the captured data can be read and displayed by smartphones and other NFC-enabled devices.

In contrast to what happens with active RFID tags, the power supply for passive HF tags comes not from batteries but from a magnetic field generated by the readout device. This field produces an induction current in the antenna of the tag. The power must be sufficient to ensure successful communication at the required distance between reader and tag.

As the data is being exchanged between reader and tag by means of the same magnetic field, this may produce in the case of passive tags communicating at HF undesired crosstalk or noise in the power supply of the tag. The noise is capable of seriously affecting the accuracy of the integrated sensor. In IMMS’ development work, the challenge was to solve this problem for the new RFID sensor tag.

Figure 2:
RFID frequencies and types. Diagram: IMMS.



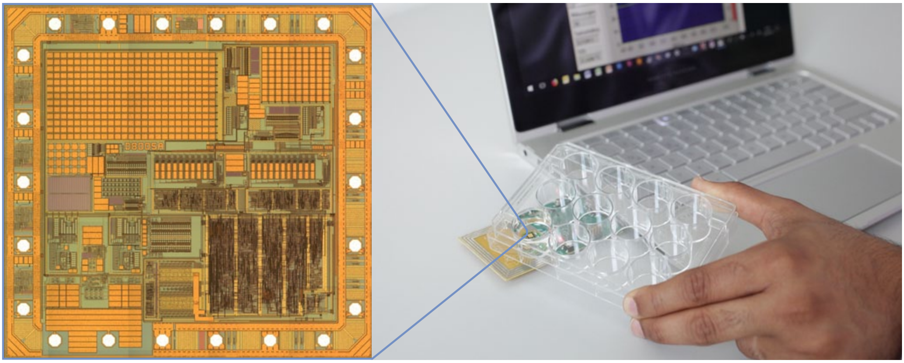


Figure 3: Passive HF RFID tag with integrated temperature sensor (left: photograph of chip; right: RFID tag with chip on the RFID antenna coil, in use for measurements in a liquid). Photographs: IMMS.

New aspects. Passive RFID for HF with integrated temperature sensor

It is current practice to construct commercially available RFID sensors from individual components, which are the detector element (temperature, for instance) connected via readout electronics and a microcontroller to an RFID transponder chip. In the case of the one-piece passive RFID temperature sensor developed by IMMS for HF, all these functions are united on a single chip. This methodology means the entire system runs under optimal power and price conditions and is suitable for miniaturised energy-autonomous wireless sensor nodes which can be used in settings which include life sciences. Figure 3 shows the complete passive HF RFID transponder for measuring temperatures in liquid environments.

Where does the challenge lie?

It is a considerable challenge to combine onto a single chip an RFID transponder and a temperature sensor while at the same time achieving the operating ranges and accuracies of commercially available stand-alone sensors. Most RFID transponder ICs which include a temperature sensor detect the temperature less accurately than separate sensors. These individual sensors operate at accuracy of ±0.15°C in a range between –55°C and 125°C. The temperature corridor in the case of RFID systems in the current state-of-the-art for HF is narrow: between 50 K and 60 K; and the accuracy not better than ±0.8°C.

This great discrepancy between the separate and the integrated type of RFID sensor tag is largely due to the noise caused by the power supply. Passive RFID systems are powered by energy generated in the HF field. As mentioned above, the noise generated thereby can seriously affect the accuracy of the sensor. Individual temperature detectors are powered without noise and are thus only exposed to interference

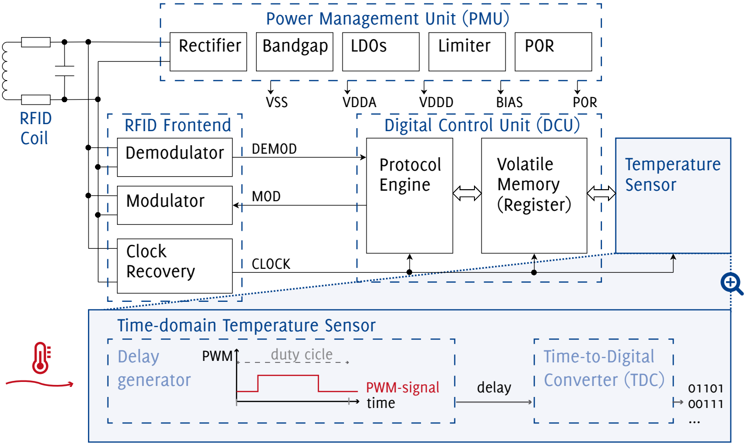


Figure 4:

Block diagram of the developed passive HF RFID sensor tag.

Diagram: IMMS.

during actual communication. This means that the integrated solution must meet the great challenge of improving the passive system to such an extent that signals are received and transmitted not only with energy efficiency but also without noise.

Chip architecture

Figure 4 shows the schematic circuit diagram of an RFID chip with a power management unit (PMU), an RFID frontend, a temperature sensor and a digital control unit (DCU). The PMU receives the energy from the magnetic field generated by the RFID reader and converts it into a stable, well-regulated supply voltage for the complete sensor tag.

The RFID frontend contains a demodulator and modulator for frequency modulation as appropriate and clock recovery for exact timing of the data streams so that the working signals go back and forth in the frequency ranges required at the particular time. The demodulator converts the modulated HF signal into a digital bitstream; the modulator shifts the response signal into the carrier frequency.

The DCU carries out the command received from the RFID and sends the response to the modulator block for transfer to the readout device. The DCU is a communication protocol engine and a volatile memory. The temperature sensor is connected to this volatile memory, which can be read and written to using RFID commands.

The schematic circuit diagram of the time-domain based low-power temperature sensor is also shown in Figure 4; it combines a digital delay generator and a time-to-digital converter (TDC). The delay generator is responsible for a pulse-width modulated (PWM) signal (i.e. signals of alternating on/off length, high and low pulse)

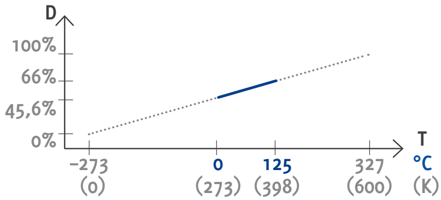


Figure 5:

Proportional relationship of duty cycle D and measured temperature T in °C (or Kelvin) for the maximum temperature range of 0 – 600 K that can be processed for the PWM signals.

Diagram: IMMS.

which reflects temperature, in that the duty cycle (the relationship between the alternating pulse widths) is directly proportional to the temperature measured, as Figure 5 shows. The TDC converts this duty cycle into a binary digital value.

Problem arising: noise rises on readout and corrupts the measured values

The supply voltage for the RFID sensor tag goes through several processing steps. First, a rectifier ensures that the alternating current generated by the magnetic field is converted into direct current. The level of the output current from the rectifier varies markedly depending on where RFID sensor tag and readout unit are situated in relation to each other. The output from the rectifier is kept to a set value by the next stage, the low-dropout (LDO) regulator, which generates the supply to the RFID sensor tag. However, it is not possible for the LDO to smooth out sufficiently the rapid voltage fluctuations caused by the RFID communication in the frequency band between 100 kHz and 1 MHz.

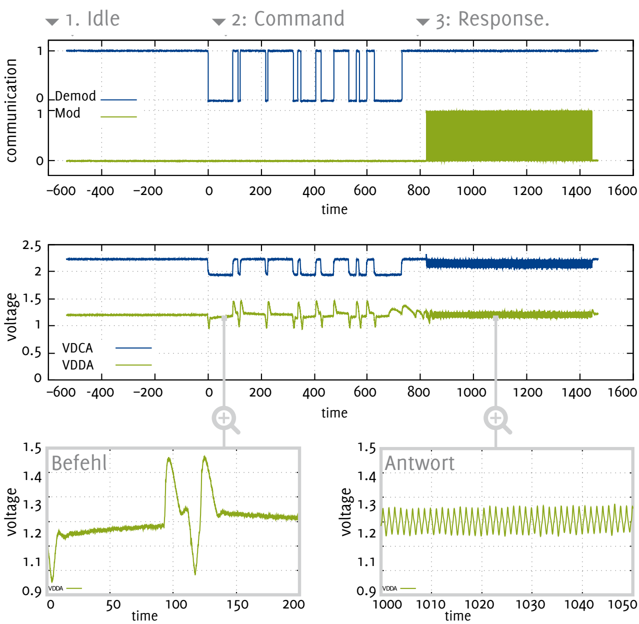


Figure 6:

Communications voltage V_{DCA} and power management voltage V_{DDA} in the chip. The signals are shown for three phases:

1. Idle,
2. Command,
3. Response.

Diagrams: IMMS.

This means that the voltage in the temperature sensor may well suffer from ripple during the HF communication, with impairment of detection.

Figure 6 shows the results of simulation for the demodulated communication signals and supply voltage on the chip. It can be seen (1) that the RFID tag is in the idle phase before the start of communication. The rectifier output voltage V_{DCA} and the output voltage as regulated by the LDO V_{DDA} still had a very low ripple of approximately 25 mV (peak-to-peak). If commands are transferred (2) from the RFID reader to the RFID tag, there is an interference effect on V_{DCA} and V_{DDA} with peak-to-peak values of 300 mV and 540 mV respectively – visible in the diagram in the lower left section of Figure 6. Also – lower right, Figure 6 – it can be seen that during the response phase (3) from the RFID tag to the RFID reader there are peak-to-peak amplitudes of 150 mV and 120 mV.

This high degree of interference affecting the LDO output voltage is due to the processes of HF communication and energy transfer in the passive RFID tag. It is at the exact moment when the readout device is transmitting a command to read out the temperature data that the measurements delivered by the temperature detector are distorted.

Solution to the problem: record a series of measurements and use only those which did not coincide with communication

Faced with this, IMMS has developed a solution enabling a single command to cause a series of measured values to be recorded and transferred. Figure 7 shows for two cases the timing relationships between the readout command, the noise in the supply voltage (vdda), the sensor output (pwm, dataready) and the response from the

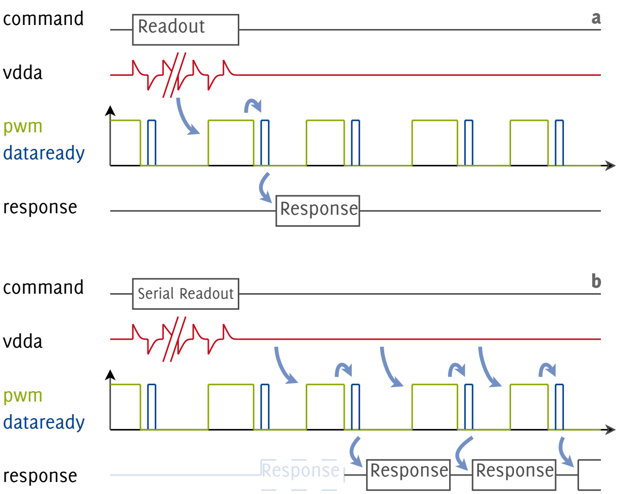


Figure 7:

(a) Single reading in standard procedure

and

(b) serial readout

shown over time.

Diagrams: IMMS.

RFID sensor tag. The two cases are standard readout and continuous readout. When the standard readout command is sent, the temperature information is returned in one action to the reader. In contrast, after the ”serial“ command a number of sets of temperature data are returned to the readout device. In both cases, the temperature sensor had already been switched ON before the readout command came, as is revealed by the activity of the PWM signal shown in green. Each time measurement has been completed and there is a new measured value ready for transfer, the signal ”dataready“ is shown.

Figure 7 (a) shows how the transfer of the standard readout command distorts the measured value that is to be sent next: the noise generated on the output voltage ”vdda“ while the measurement is being taken leads to an error in the rising edge of ”pwm“ which alters the ratio. Thus, in the case of single readings using the standard readout method, the response from the RFID temperature detector is always affected by interference.

Figure 7 (b) shows the response to a serial readout command requiring several sets of data to be sent one after the other to the reader. Here it is clear that the data arriving after the second response is not affected by the voltage interference due to the readout command because there is no HF communication coming at that time from the reader. There are still errors after the second response because of supply noise generated by the communication from the tag while it responds, but this noise has much less effect on the measurement. Furthermore, the RFID reader is capable of applying an averaging procedure to series of values transferred, reducing the residual inexactitude so much that it barely affects the measuring accuracy of the complete system.

Measurement, characterisation and calibration

The comparative measurement results are given in Table 1. They show the RFID sensor achieving resolution of 9.01°C in the case of single readings but of 0.56°C for serial readings. This is confirmation that it is the voltage fluctuations caused by the standard readout command which are the main source of error in sensor accuracy. Using serial communication improves the accuracy by a factor of 16. Nine samples of the integrated chip RFID sensor were subjected to the complete measurement process in a temperature chamber. After two-point calibration at 20°C and 100°C the error interval is reduced to ±0.2°C. If the tolerance limits are set to 3σ, i.e. an error

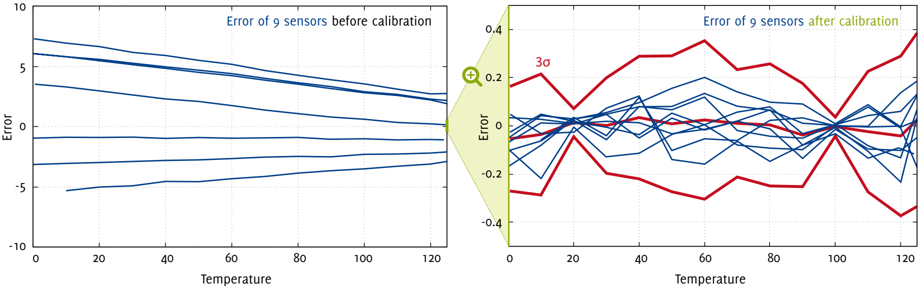


Figure 8: Measurement error for 9 sensors (a) before calibration and (b) after two-point calibration at 20°C and 100°C; the red line relates to the average tolerance of 3σ. Diagrams: IMMS.

probability of 0.27%, the measurements are accurate to ±0,4°C in the range from 0°C to 125°C. The results of this characterisation are shown in Figure 8.

Procedure	Resolution (°C)	Main source of error
Standard readout	9.01	Voltage interference
Serial readout	0.56	Noise at sensor

Table 1: Resolution achieved by different commands.

To improve its measurement accuracy, the sensor is calibrated. The user exposes the detector to a known temperature, records the measured value and uses computer software to mathematically map this value to the expected value. Two-point calibration of the detector involves using two known temperatures, measuring the detector's reaction and asking the software to recalculate the original values against the newly calibrated ones. Figure 8 shows the error for the nine sensors (a) before calibration and (b) after the two-point calibration at 20°C and 100°C.

To take an example, if the temperature has to be kept constant at above 68°C for a particular cell culture, the RFID sensor tags are calibrated to an accuracy of 0.5°C at 68°C. If the tag were only accurate to 1°C, the user could not be certain that the temperature had been correctly regulated to 68°C.

Future prospects

These temperature detectors as passive RFID sensors operating at HF have the potential to enable measuring processes of the life sciences to be digitised, automated and carried out with the aid of smartphones and other easily-available NFC-enabled end devices. Even beyond this, the passive integrated RFID sensor chip developed by IMMS will cope with the high demands of the ultra low power (ULP) systems

More on test and characterisation at www.imms.de.

More on ASIC development at www.imms.de.

which are necessary in IoT and Industry 4.0 applications. The great advantage of passive RFID sensor tags is that they require neither maintenance nor an outside electricity supply and can thus be integrated into a wide variety of application scenarios. IMMS is currently concentrating on improving the sensitivity of the tag and the power consumption of the chip. The Institute is also, in the ADMONT project, developing a modular sensor system, an RFID bridge ASIC, which will connect a variety of commercially available sensors provided with standard interfaces to a multiplicity of applications in industrial settings.

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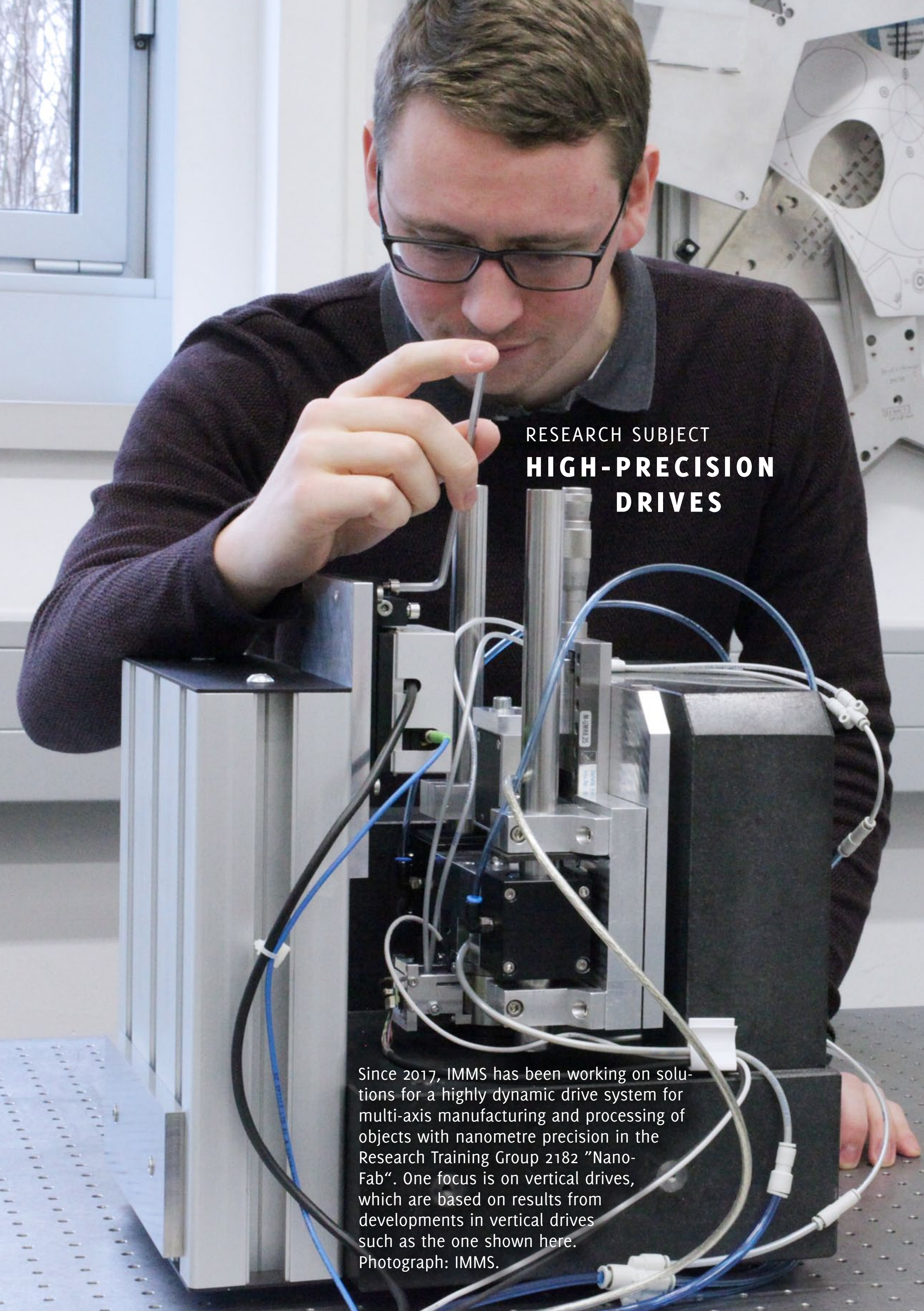

RESEARCH SUBJECT

HIGH-PRECISION DRIVES

Since 2017, IMMS has been working on solutions for a highly dynamic drive system for multi-axis manufacturing and processing of objects with nanometre precision in the Research Training Group 2182 "NanoFab". One focus is on vertical drives, which are based on results from developments in vertical drives such as the one shown here. Photograph: IMMS.

The continuous reduction in the size of the structural elements of technical products in many different sectors increases the demand for precision machinery with which tiniest structures and objects can be measured and manufactured with high accuracy. There are many such objects having spatial extents from millimetres to centimetres, while surface characteristics and functional elements are just a few microns or nanometres in size and have to be positioned with a precision less than one nanometre in the production process.

To blaze the trail for the manufacturing of components from the macro-world with the precision that is associated with the micro- and nano-world, we conduct research on the scientific fundamentals and technical solutions to implement nanopositioning systems acting over long distances of travel. Our highly dynamic integrated multi-coordinate drives move objects with the same accuracy over distances of several hundred millimetres within the shortest time. Our solutions are intended for use under vacuum, in cleanrooms and sites with particular requirements for thermal insulation and elimination of vibrations.

Projects in the field of high-precision drives: www.imms.de.

Highlight of 2017 in our research on high-precision drives: NanoFab* graduate college begun

30 PhD students have been working in the NanoFab Research Training Group (RTG) 2182 since April 2017 on a project funded for 4.5 years by the DFG (German Research Council). IMMS has one of the researchers; the work is on tip-based and laser-based three-dimensional nanofabrication techniques applied to large (macroscopic) areas. The supervisors of the PhD students are teaching and research staff of Ilmenau TU and IMMS under the leadership of the Institute of Process Measurement and Sensor Technology which is concerned with sensors and process measurements in manufacturing in the Mechanical Engineering Faculty.

NanoFab at www.imms.de.

Nanofabrication – not used up to now for large objects and still without error correction

The RTG is investigating techniques of manufacturing that will in future enable macroscopic objects to be made to the nanometre scale of precision in ever more fields of manufacture. Admittedly, it is already possible to produce structures below ten nanometres using nanofabrication, but an object area of only a few hundred square micrometres is the limit, and speeds are slow and accuracy limited. The particular challenge being taken up by the NanoFab RTG is that error correction should be able to take place even while the nanofabrication is running; to date, straight measurements have been possible, but in-process correction has not. Currently, if static or dynamic deviations of position arise during nanoproduction, among the problems they cause, are errors in the geometry, irregularities in shape or roughness in the structures or objects – all of which can be established only with hindsight.

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There are six investigative subprojects, with the NanoFab TSG working on a variety of fronts in around the practicability of freeforms manufactured in 3D at nanometre precision and with in-process error correction. The fronts include theory and metrology, tools and parallelisation, kinematics and control: control is relevant in lithography, optical microsystems, real-time process management and multi-dimensional drive and positioning dynamics.

IMMS at work on highly dynamic nanofabrication drives

At the Institute, a drive system is being explored that permits multi-axis manufacturing and processing of objects with nanometre accuracy. In such a drive, extremely even and smooth movement must take place in the complex spatial trajectories dictated by the geometry of what is to be fabricated.

To achieve high machining speeds, the entire drive system (actuators, guides, sensors, amplifiers, control) must be able to execute the set points with minimal deviation and extremely fast. It will be necessary to develop drive systems with near-perfect reproducibility and synchronism if multi-axial nanofabrication of relatively large objects is to be achieved. 3D-positioning of objects is already possible; further degrees of movement are necessary, actuators and sensors need to be integrated into the drive structure and controls.

The research emphasis is on synchronicity in the movements, temperature maintenance, minimal power dissipation and minimisation of drive and disturbance forces. In these innovative drives for nanofabrication, what is crucial is highly dynamic drive and positioning capable of being adapted to the motion required, so that the consequences for drive, controls and overall dimensioning must all be taken into account.

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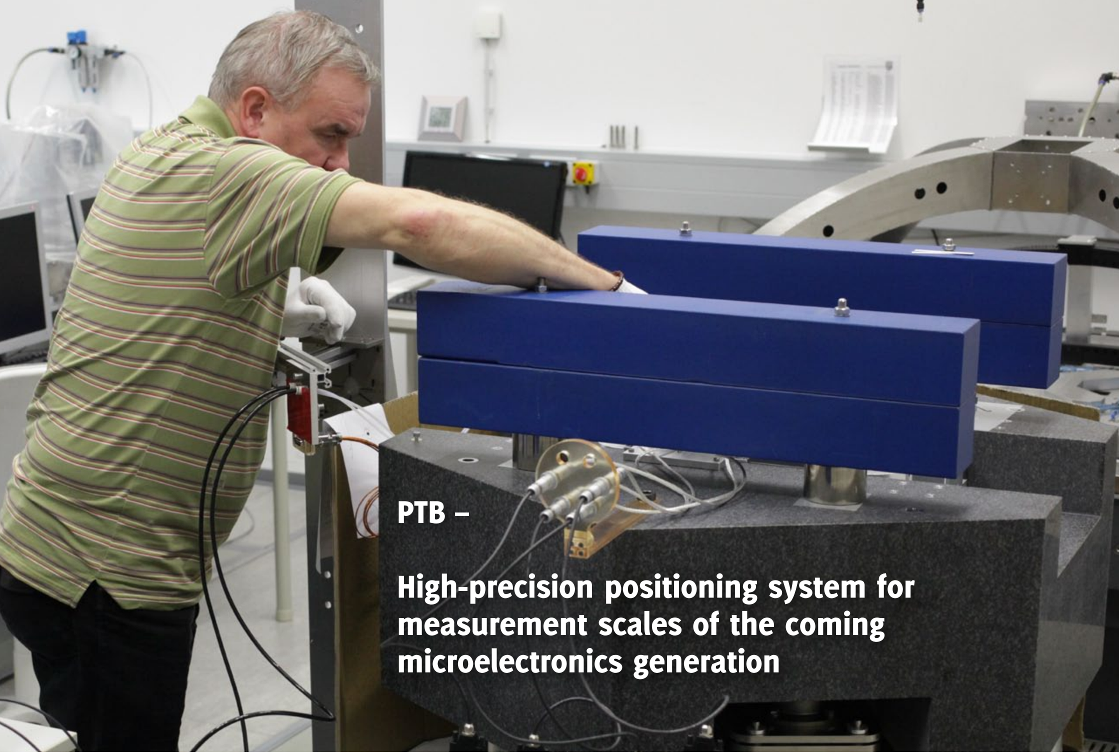

PTB –

High-precision positioning system for measurement scales of the coming microelectronics generation

Work at IMMS for the Physikalisch-Technische Bundesanstalt (PTB) on a nanometre-precision planar drive system for a large travel range and use in vacuum. Photograph: IMMS.

Objectives and overview

If no way of measuring on atomic scale, no future for high technology

Our daily lives are both accompanied and influenced by microelectronics. They are hidden in smartphones, in all automated and networked forms of production and in the IoT, the Internet Of Things. As they shrink in size, they also acquire more smart functions, and thus an ever greater number of structures on a single chip. As a result, semiconductor manufacturing has to cope with ever narrower structures – currently, breadths of ten nanometres. If there are to be structures of this size and, in future, yet smaller, on a chip, modern production and inspection plant will have to be able to carry out measurement and positioning in the sub-nanometre range. There will be a need for linear scales or two-dimensional grid structures used in this manufacture to be correctly calibrated. With this in mind, the PTB (the German National Metrology Institute) in Braunschweig (also known in English as Brunswick), which is the highest technical arm of the German Ministry for Education and Research, the authority on all questions of correct and reliable measurement, is at work on the problem. The PTB is constantly developing measurement procedures and instruments of increasing accuracy so that they can be used as the reference systems for measurement calibration standards in the above applications and countless others.

Laser interferometers measuring long distances in vacuum require high-precision drives

Of crucial importance is the role played by accurate measurement of distance with laser interferometers, as they are a means of achieving measurement uncertainty down to the nanometre for even relatively long stretches exceeding 100 mm. As a result, one of the PTB's major research aims is to investigate and optimise laser interferometer properties, particularly focussing on sources of error.[1] In atmospheric conditions, the changes in the refractive index of air due to temperature, pressure and humidity changes are the biggest error factor, masking many others. Investigations are, therefore, increasingly carried out in vacuum.

For this demanding research, the PTB needed a planar stage with a large processing area capable of use in a vacuum as a system to help bring into position the individual components of the interferometer being examined with nanometre accuracy, so that predefined, precise and reproducible measurement conditions could be ensured. The stage would have to move with total regularity and absence of vibration through an area 150 mm x 2 mm, while having minimum influence on the measuring space. What is more, particular importance is laid on an absolute fit with the complex measuring equipment found inside the vacuum chamber, where there will also be a 3D positioning unit to raise the z position and the pitch axis very slightly.

IMMS planar drive system works in vacuum

To meet these needs, IMMS has developed an air-guided planar drive with an optical incremental measuring system, see Fig. 1. This motor uses closed-loop control for the slider's position in the x,y (Cartesian) plane and for the rotation around the vertical axis (φ_z). The remaining degrees of freedom for the slider, i.e. the vertical (z) movements and inclination around the horizontal axes (φ_x, φ_y) are defined by a planar aerostatic slider guide with three flat air-bearing pads. The 3D stage is carried by the planar stage and offers the possibility of positioning the object to be measured by raising it across a small range within these degrees of freedom.

IMMS worked not only on developing and creating the stage as hardware but also on the control algorithms, which it then integrated into an operational control system with its own 3D closed-loop control. The control software was implemented in hardware capable of real-time open-loop control which is in communication with

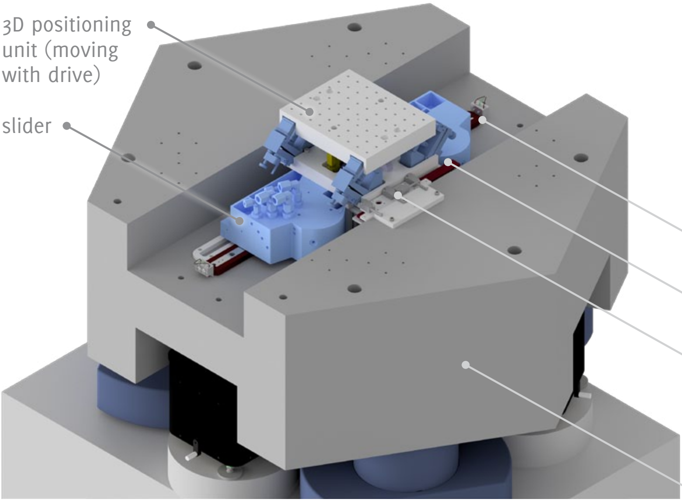

Figure 1:

Main components of the planar drive system (CAD). Diagram: IMMS.

the upstream controls of the overall experiment as client, so that the planar drive system was integrated into the full experimental setup as an independent subsystem. The new drive system has as its core function the precise positioning of the object to be measured but also enables the slider to be locked down temporarily with ensuing deactivation of all the systems: for that period, outside influences on the measurement environment are further reduced. The drive has been in use at the PTB since mid-2017 for the investigations described.

More on open- and closed-loop controls at www.imms.de.

More on actuator systems at www.imms.de.

The IMMS solution in detail

Drive

The principle on which the new system rests is that of an integrated multi-coordinate drive.[2] As is shown in Fig. 2, a planar drive has been created in which several linear actuators affect a single object simultaneously. The interaction of the actuators can generate horizontal slide in any direction so that the x or y coordinate can be modified as desired. At the same time, the actuators generate torque around the vertical axis and thus control the yaw, i.e. the rotation φ_Z of the slider. Each of the actuators is made up of flat coils fixed to the drive and its associated electromagnetic circuits on the underside of the slider. As the range of movement, 2 mm, is tiny, single-phase drive units were employed for the y direction. For the x direction, which extends for 150 mm, a two-phase system was used. The coil currents are commutated to reflect the slider position so that there is an exclusively horizontal slide exerted at every position on the magnetic bridges or, as appropriate, the slider.

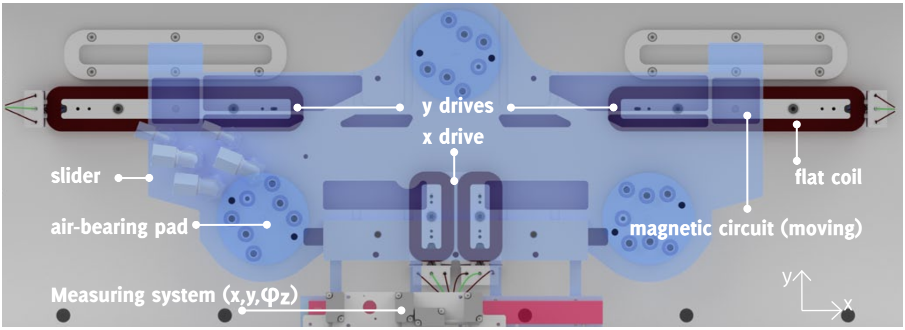

Figure 2: Basic structure of the planar drive (the slider is shown as transparent). Diagram: IMMS.

Guide mechanism

To guide the slider, three special flat air-bearing pads which consume a minimum of air and have a minimum of leaks are used. The compressed air supplied to them enables the pads to create a bearing gap of approx. 5 µm, i.e. the slider and pads float approx. 5 µm above the extremely flat granite stator. It is thus possible for the slider to move in the horizontal level to all effects without friction or vibration or stick-slip. The air from air pads is conducted away through surrounding grooves so that there is no leakage into the vacuum environment.

Measuring system

So that the planar stage can be controlled by closed loop during operation, the movement of the slider in the relevant directions (x, y, φ_z) is measured without contact and with very high accuracy. For this purpose, an optical measuring system made by Heidenhain is used that has as its physical scale a Zerodur-glass-ceramic 1-D-plus scale. This special "ruler" has a linear encoder for both the x and the y direction. Together with three fixed measuring heads, it ensures high-resolution, accurate measurement of movement in all three directions, x, y, φ_z. A fourth measuring head is also present which is used to initialise the rotational position when the motor is started up but is switched off for the duration of the actual measurement operations. This is in order to keep any warming of the system as low as possible.

For the same purpose, a lock-down function was integrated into the drive system. If the measuring task demands it, the slider can be locked down at any position within its travelling range. The air-bearing pads are inactivated appropriately to enable the slider to be "set down" on its stator in a controlled manner. After the air pads, the position control and measuring system are deactivated, so that, for the duration, the stage is a purely passive system within the measuring space. After any desired period, the system can be reactivated using the stored position measurement data and the slider can again be raised at its lock-down position for operation. This is the lift-up function.

EDP control system

The whole drive system contains not only the drive, its guide and its measuring system but also the control system supporting electronic data processing together with corresponding control algorithms. Separate axis controllers on a PID basis (proportional integral differential) were created for the three degrees of freedom and optimised by means of control path identification. Central state control of the process organises the interaction among all the electronic components: for instance, stopping points, closure valves, pressure monitors and measurement signal monitors. The user can thus operate the system using commands and status queries about positioning that are script-based.

Results and positioning performance

The drive system created has parameter and positioning features as summarised in the following table:

150 mm x 2 mm	Area travelled
max. 10 mm/s	Travel speed in x, y
300 mm/s²	Acceleration of positioning in x, y
2,5 nm	Resolution of measurement in x, y
0,042 µrad	Resolution of measurement φ_Z (2,5 nm @ 60 mm sensor offset)
5 kHz	Sampling frequency of control electronics
ca. 25 kg	Mass moved

In Fig. 3, there is a photograph of the drive system on completion, taken at IMMS during commissioning. This took place initially in atmospheric conditions. At this stage a crucial step was the design and implementation of an initialisation procedure that would enable not only the two reference markings on the scale for x and y to be logged as reference but also the degree of rotation of the slider around the vertical axis (φ_Z).

Following this, the real-time programs for open- and closed-loop control which had been prepared were transferred into the control electronics and launched. It was now possible to determine the actual features of the movement, such as eigenfre-

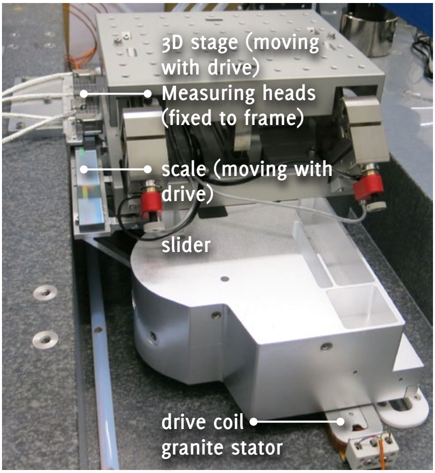

Figure 3: The planar drive system during commissioning at IMMS. Photograph: IMMS.

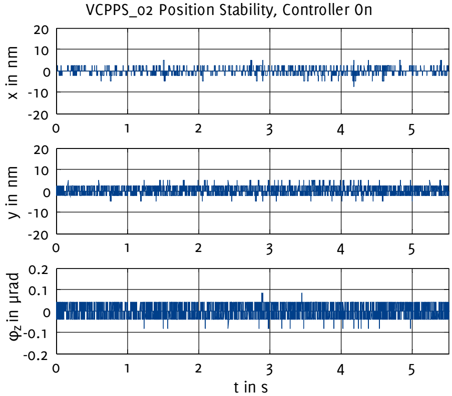

Figure 4: Signals over time from x, y and φ_z positions while under control for setting (x,y)=(0,0). Diagrams: IMMS.

quency, disturbance and environmental vibration, optimising the closed-loop structure and parameters on the basis of these figures and thus fulfilling the demanding specifications for the positioning features.

Fig. 4 shows the time signals for the x, y and φ_z measurements during operation at lock-down in a defined position and clearly shows how stable the nanometre positioning of the planar drive is. The RMS is below three nanometres. In Fig. 5 there is an example of the position and speeds during movement along the x axis at an intended speed (v) of 1 mm/s. The principle of a direct drive, the minimal disturbance and the optimisation of the control structure and the control parameters all work together to ensure high constancy of speed and extremely low lateral deviation from track, again within the nanometre range.

The main positioning characteristics achieved are listed in the table below:

Scenario	Parameter	Value
Closed-loop control on, lock-down at defined position	RMS in 2D	< 3 nm
Closed-loop control on, travel v=1 mm/s	RMS for speed	< 0,5 %
Closed-loop control on, travel v=1 mm/s	RMS for deviation from track	< 10 nm
Lock-down of slider at defined position	Deviation of lock-down position	< 0,5 µm

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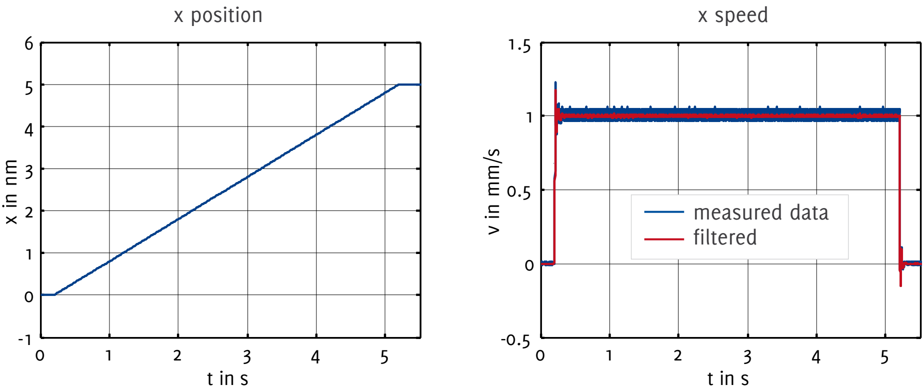

Figure 5: Time signals and speeds during movement on x axis (travel from x = 0 mm to x = 5 mm, v_{soll}=1 mm/s, RMS deviation in speed: 4.2 µm/s*) 4,2 µm/s*) *Filter used for determining speed: bandpass filter with pass up to 200 Hz, stop after 300 Hz. Diagrams: IMMS.

Future prospects

The highly accurate positioning system here presented was commissioned following integration into the complex interferometer testing apparatus as a sub-component in mid-2017 on site at Braunschweig and in intensive collaboration with the Dimensional Nanometrology Department of the PTB. As a result, the PTB now has what is basically necessary for sophisticated systematic investigation of sources of error in laser interferometers. The system has already proved itself very useful in initial experiments and has assisted in identifying sources of error at the sub-nanometre level. The planar drive developed at IMMS is thus making a valuable contribution to the establishment of the calibration standards which will be applied to manufacturing and inspection machinery for the micro-electronics of the coming generation.

More on actuator systems at www.imms.de.

More on open- and closed-loop controls at www.imms.de.

Projects in the field of high-precision drives: www.imms.de.

Contact person: Dipl.-Ing. Steffen Hesse, steffen.hesse@imms.de

1 C. Weichert, P. Köchert, S. Quabis, J. Flügge: A displacement interferometer for the calibration of the silicon lattice parameter. Proc of 17th EUSPEN, 2017.

2 S. Hesse, C. Schäffel, H.-U. Mohr, M. Katzschmann, H.-J. Büchner: Design and performance evaluation of an interferometric controlled planar nanopositioning system. In: Meas. Sci. Technol. 23 074011, doi:10.1088/0957-0233/23/7/074011, 2012.

3 C. Weichert, S. Quabis, J. Flügge: A new vacuum setup for fundamental investigations on interferometric length measurements, accepted for 18th EUSPEN, 2018.

Figure 1: Commissioned by the VPCI of Leipzig University, IMMS has created a prototype device (right) for automatic sexing of eggs. The starting point was the specifications from VPCI experience with manual devices (left) configured for individual testing. Photograph (left): Professor Almuth Einspanier and Dr. Anne Weißmann. Photograph (right): IMMS.

Objectives and overview

For want of a cheap enough alternative, millions of male chicks are being destroyed

In the German poultry industry alone, 40 – 50 million male day-old chicks are killed each year because they neither lay eggs nor yield much meat. This killing is because the poultry industry divides domestic hens into two types, those with high egg-laying rates (known as layers) and those which put on a lot of flesh in a short time. Animal protection laws state that animals are not to be killed without good reason. There is great controversy as to whether and how far commercial motives should be permitted to outweigh this ethical consideration. Policies are being developed to banish chicken shredders and several of Germany's federal Länder have already forbidden them by law. The law will, however, be applied only when there are viable alternatives.[1] There have been many different approaches all over the world for many years in the attempt to find a solution which might harmonise animal welfare and mass production.[2]

1 *See https://www.sueddeutsche.de/wirtschaft/kuekenschreddern-das-gemetzel-geht-weiter-1.3924618*

2 *Overview of the solution approaches in: "In-ovo-Geschlechtsbestimmung bei Legehybriden mittels endokriner Analyse der Allantoisflüssigkeit", Anne Weißmann, Leipzig 2014, http://ul.qucosa.de/api/qucosa%3A12496/attachment/ATT-0/*

Automated sex determination before hatching – one possible way out

Commissioned by the VPCI (Institute of Physiological Chemistry, Faculty of Veterinary Medicine) of Leipzig University and under their instruction, IMMS has gone from the drawing board stage to proven use of a prototype device for automatic sexing of eggs. So that full automation of the hormone-based procedure developed since 2011 in Leipzig and validated in practical testing may follow. The automatic equipment is based on the experience gained by the VPCI on manual devices for individual egg testing. The central specification was that the eggs should be positioned at an angle of 45° to their longitudinal axis and that samples should be removed from above by a vertical puncture (see Figure 1, left). The IMMS prototype sampling device working automatically in parallel lines is an initial step on the road to future automatic testing of vast numbers of hens' eggs in egg-producing factories so that male eggs can be sorted out automatically before they hatch.

The endocrinological procedure at Leipzig University

The science behind the Leipzig procedure is endocrinology. The procedure is to remove a drop of the embryo's urine (known as the allantoic fluid) through a tiny puncture in the egg shell made with a fine canula at a stage which researchers currently believe to precede sensitivity to pain for the embryo. Sex-specific differences in the hormones of the allantoic fluid sample of nine-day-old embryos are tested for, using oestrone sulphate as marker. If the hormone is found, the egg will develop into a female bird. If it is not present, the embryo is male and the egg will not be hatched. The hole made in the egg shell has no influence on the further development of the female embryo and does not require closure.[3] In manual pricking and sampling of 10,678 eggs on the ninth day after laying, this procedure achieved 98 % accuracy in the predicting the sex. No significant variation in chicken body weight was detected on hatching. Breeder farm experiments confirmed all the usual egg-laying parameters.[4]

IMMS' Prototype 1.0

Prototype 1.0 in a video via www.imms.de

In close collaboration with Professor Einspanier of the VPCI, IMMS came up with a device and system for the automation of the hormone-based procedure, including

3 See ibid.

4 See "Anwendungsorientierte Untersuchungen zur endokrinologischen In-ovo-Geschlechtsbestimmung beim Haushuhn", Prof. Dr. Almuth Einspanier, Institute of Veterinary Physiology and Chemistry, Leipzig University, https://www.hs-osnabrueck.de/fileadmin/HSOS/Homepages/Angewandte_Gefluegelwissenschaften/pdf/2017_8._Geflsymp_Einspanier_30.05.2017.pdf drive mechanics and system control. The first tester, for 75 eggs per tray in the first instance, succeeded in automating the extraction of allantoic fluid from hens' eggs and preparing it for sex determination, including full matching of sample to egg. Up to the time of writing, the tests had been carried out for 2,100 eggs by Leipzig University in cooperation with the REWE supermarket group using the prototype. The hatching rate was 86.5%, sampling success was 89.5% and for 95% of the samples the hormone-based diagnosis was correct.[5]

Further development is going on using the principle of the prototype tester to achieve higher throughput and even higher sampling success in a joint venture (known as SELEGGT) between REWE Group and the Dutch HatchTech company.[6]

The IMMS solution in detail

Initial experiments on mechanical pricking of the shell and fluid sampling

In reliance on Professor Einspanier's experiments carried out over a number of years, the idea was to attempt automation of the pricking of a tiny hole into each egg and removal of allantoic fluid. As manual practice is to press a fine point carefully into the egg shell, the first experimentation was in dropping a pointed object of specific weight from a specific height to puncture the shell. Experimental measurements were made for different pointed objects, weights and drops. If there is not enough kinetic energy available, the egg is not punctured. If there is too much, the egg shell is crushed by the impact.

Tests were also made to find out whether different tools are needed for puncturing and removal or whether a single element can succeed in both making the hole and drawing out the liquid. Whereas the puncturing was reliably solved with a hardened point, the experiments using a cannula in a variety of materials, sizes, wall thicknesses and angle of sharpening proved very difficult. There were long series of tests before a needle was found in material that would be rigid enough when the dimensions included a small enough external diameter and large enough internal diameter. It was possible to carry out both the puncturing and sampling in a single step using this cannula.

More on actuator systems at www.imms.de.

More on open- and closed-loop controls at www.imms.de.

5 *Souce: Leipzig University, Institute of Veterinary Physiology and Chemistry.*
6 *https://www.topagrar.com/news/Home-top-News-Geschlechtsbestimmung-beim-Ei-bald-praxisreif-8395092.html*

Figure 2: Hens' eggs on trays which are employed in the poultry industry. Each level (i.e. tray) has on it 150 eggs being hatched. Photograph: Professor Almuth Einspanier and Dr. Anne Weißmann, VPCI.

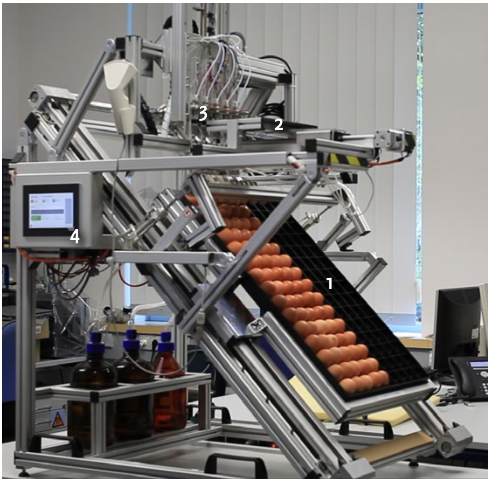

Figure 3: In-ovo tester made by IMMS, Prototype 1.0: (1) holder for one tray (15 rows, 5 filled columns for 75 eggs), (2) holder and actuator for titer plates, (3) puncturing module, (4) display and operating unit. Photograph: IMMS.

Specifications for the mechanical procedure

Professor Einspanier provided the specifications for the mechanics and these were regularly brought up to date in the course of the collaboration. It is necessary for a tray to be taken out of the incubator at a predetermined time before the tenth day of the incubation period and then put into the prototype machine. There is a photograph of the incubator arrangements in Figure 2. What should follow is automatic removal of allantoic fluid from all the eggs on the tray and orderly transfer of the samples into an appropriate titration board. The ensuing steps are done manually: the liquid is subjected to hormone analysis. The eggs with male embryos are put aside and the tray with the remaining eggs is returned to the incubator. It must be ensured that the sampling of eggs in subsequent trays is carried out with equipment clear of all traces of earlier samples. Also, the entire plant must be kept germfree.

Structure of IMMS' Prototype 1.0

Prototyp 1.0 in a Video via www.imms.de

IMMS put together as Prototype 1.0 an in-ovo tester to sample allantoic fluid and transfer it to a titration plate automatically, see Figure 3. The basic items in the in-ovo tester are the seating for a tray which has in it 75 eggs in 15 rows and 5 columns, plus another bed and the actuator equipment for the titration plates which will receive the liquid samples. It also had to include some mechanical means of carefully handling and positioning the eggs, a puncturing module and a computer display with controls. There was cleaning and drying equipment for the cannulae in order to avoid cross-contamination. The necessary hygiene was ensured by installing a UV lamp to maintain general sterile conditions while the tester is out of action.

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Automated actions of the in-ovo tester

No one egg is the same as another – device to accommodate natural variations

So that allantoic fluid can be removed from the egg near the air sac, it is brought into position below the puncturing module. The eggs are placed in the prototype machine at the same angle as in the incubators, with the air sac at the top, see Figure 2. The highest point of the egg is the puncturing position through which it is planned to remove allantoic fluid. However, even if all the eggs in the tray are in the right position, they are nonetheless of various sizes. Multiple measurements were logged and tables drawn up to document the variations. Clearly, the five eggs to be punctured simultaneously offer the point at different heights. This means the needles on a descending module would have to start from different positions to impact the each egg with the correct drop. A mechanical egg puncturing unit of this kind would be complex, expensive and likely to break down. Also, the egg would be loose in the tray, so that it might roll during puncturing, with possible damage to needle or egg.

To solve both problems, the principle must be turned on its head. The eggs to be sampled are gently raised out of the tray and brought into contact with a stop bar, see Figure 4. In this way, the surface of every egg is at the same height in relation to the puncturing module. Additionally, pneumatic pressure is applied to the egg to keep it in contact, so that it can no longer roll. Guide plates at the sides also assist correct positioning during the lifting process.

Prototype 1.0 in a video via www.imms.de

Figure 4: By raising and pushing eggs of different sizes against a stop, the surface of each egg is at the same height in relation to the puncturing module and held steady for puncturing. Photographs: IMMS.

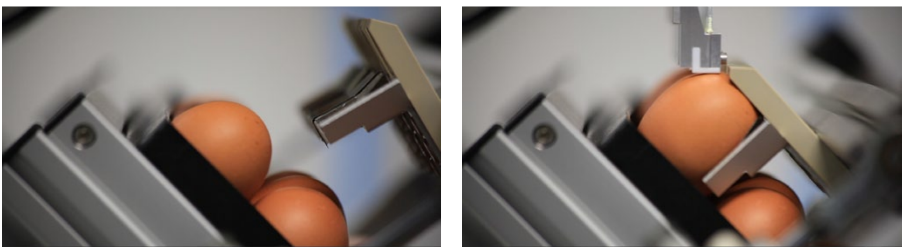


Figure 5:

Puncturing modules with needles and hoses for suction of fluid for testing, also photoelectric sensor to detect clear liquids.

Photograph: IMMS.

Now it is the length of the needles that ensures the depth of puncturing is exactly as specified. The point of puncturing and the point of contact are very close to each other and as the egg-stop on the bar is circular in shape, one is within the other, so that the curvature of the egg surface makes no difference.

Sampling and matching of sample to source

Despite the tiny cross-section of the needles, it is possible the allantoic fluid can be drawn up by suction. The amount of liquid withdrawn is established by a scale in the hose immediately behind the needle, see Figure 5. A photoelectric sensor capable of registering clear liquids signals that the vacuum can be switched off and that the hose sealed so that the liquid does not run back out.

The titration board moves into position automatically beneath the module with the five needles, so that the samples are transferred into the correct receivers as the puncturing module is lowered, see Figure 6. The eggs are replaced in the tray, which then advances by one row. While this is happening, a cleaning cycle takes place. The needles are rinsed with cleaning fluid and then dried. This serves to prevent samples mixing together and suppresses possible contamination with germs.

When all the eggs have been removed from a tray, the machine returns to starting postion and the tray and ti-

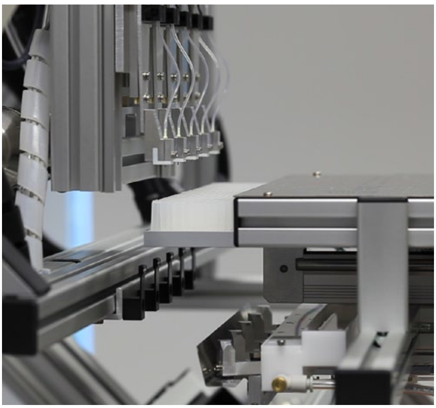


Figure 6:

The titration board is brought automatically under the five needles enabling the samples to be transferred into the cuvettes at the right positions. Photograph: IMMS.

Prototype 1.0 in a video via www.imms.de

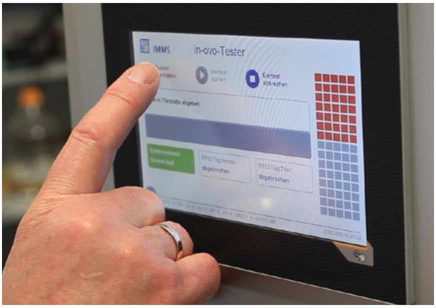


Figure 7: user interface programmed by IMMS for the in-ovo tester. Photograph: IMMS.

tration boards can be exchanged. The operator receives the appropriate commands from the user interface which has been designed by IMMS, see Figure 7. So that the samples and eggs are correctly linked, each tray and each titration board has an RFID tag. These tags are read with a hand scanner at the start of each work cycle.

Results of project

IMMS brought much knowhow on drives and the development of systems to bear when designing the tester. In particular, it was a question of effective step motors, process controls and process programming combined with pneumatic drives, touchscreen programming and optical means of measurement for the doses of extracted liquid. The constant dialogue with Professor Einspanier also meant that the project raised IMMS' profile of competence in the development of life-science applications. All this contributed to the success of the procedure of automatically sampling allantoic fluid from hens' eggs during the incubation period for purposes of sex determination. Once created, Prototype 1.0 was successfully tested in major experiments and has been handed over to the VPCI to serve as the basis of further development. For instance, the automation of the hormone investigation, the egg removal and the mechanical handling of the trays were outside IMMS' remit. Partners of the VPCI in possession of particular knowledge of commercial egg laying have already moved the IMMS prototype on to new versions after the start on automation provided by IMMS. All in all, the path is now open to an alternative to killing male day-old chicks so that in future there may be closer harmony between mass production and the principles of animal welfare.

More on actuator systems at www.imms.de.

More on open- and closed-loop controls at www.imms.de.

Projects in the field of high-precision drives: www.imms.de.

Prototype 1.0 in a video via www.imms.de

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

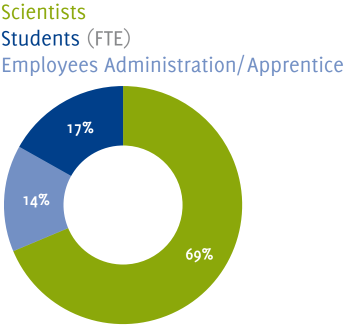
IMMS produced Prototype 1.0 for automated sampling of hens' eggs to enable endocrinological sex determination on being commissioned to do so by the VPCI (Institute of Physiological Chemistry in the Faculty of Veterinary Medicine) of Leipzig University. The project was funded by the BMeL (Federal German Ministry of Food and Agriculture) under the code 313-06.01-28-1-33.031-07.

PROOF THROUGH FACTS AND FIGURES

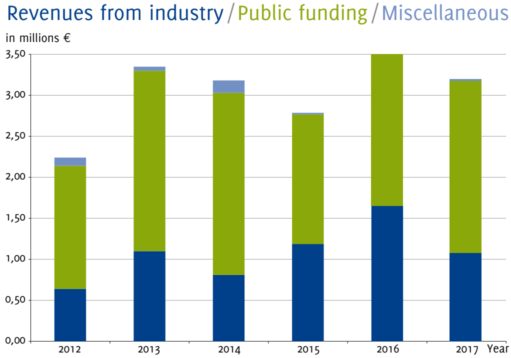
Preparing to take measurements in the cleanroom measuring lab at the Erfurt section of the Institute. Photograph: IMMS.

Facts and Figures 2017

Staff:



Project income:



2017 saw 85 members of staff working at IMMS. There were 57 employed as scientists and 14 (FTE) students, i. e. 83% of the entire staff, who were directly involved in research and development.

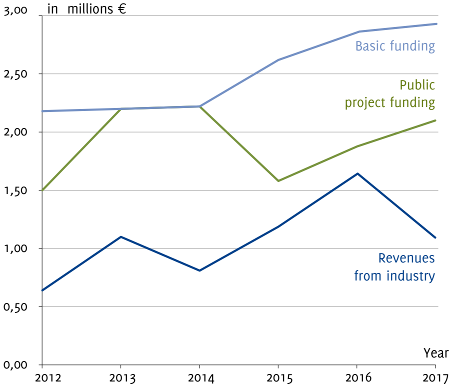
The 14 full-time equivalent student posts were actually filled by 41 students in all who were taking the opportunity offered by IMMS to deepen and supplement their studies by practical research. There were 9 students on formal internships and 23 working as paid assistants. IMMS was supporting and supervising 6 dissertations for the BSc and 3 for the MSc. 8 of the present staff are inscribed as doctoral students at a university.

By engaging in undergraduate teaching with such commitment, IMMS is, of course, able to attract onto its staff enough of the highest quality graduates.

Income from publicly funded projects rose by 11% and the income from industrial commissions dropped by 16% in 2017 against the previous year. The earnings proportion is 59%. There were 15 research projects in the service of industry completed to plan up to mid-2018. Taking into account changes in inventories, the actual performance in 2017 was a rise of 17% on the previous year. This proportion is reflected in the income trend. Income from project funding rose by 12%. The circumstances mentioned above meant that income from industrial commissions was 34% less than it had been in 2016.

More on funding at www.imms.de.

Pillars of financial support



For the coming three years (2018 – 2020), IMMS is expecting growth in both areas. This is due in great part to the Institute's strategy of rising consistently to the demand for its skills and products found in commerce and society.

The great majority of IMMS projects is carried out jointly with industrial partners, which is evidence of how well IMMS is accepted in the research partner role. 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. SMEs are the primary beneficiaries. 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 – for this, IMMS is excellently placed.

Again in 2017, Thüringen was a support to the Institute, ensuring that external conditions remained reliable. The work IMMS could do in conjunction with regional SMEs benefited above all from this.

Scientific Advisory Board

Supervisory Board (Chair: TMWWDG[1])

Proprietor German "Land" of Thüringen

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Univ.-Prof. Dr. Ralf SOMMER

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Anne ARLT/Beate HÖVELMANS

Administration
Jutta WIEGEL[+]/Mario GÖRLACH[++]

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Holger PLEß

Mechatronics
Dr.-Ing. Christoph SCHÄFFEL

System Design
Dr.-Ing. Tino HUTSCHENREUTHER

Industrial Electronics and Measurement Technology
Dr.-Ing. Klaus FÖRSTER

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- **Chairman:** [1]Robert FETTER, Ministry for Economic Affairs, Science and Digital Society Thüringen (TMWWDG)
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- Dr. Jens KOSCH, Chief Technical Officer, X-FAB-Semiconductor Foundries AG
- Andreas ROHWER, Ministry of Finance Thüringen
- Univ. Prof. Dr.-Ing. habil. Kai-Uwe SATTLER *(since 01 October 2017)*, Pro-rector for Science, Ilmenau University of Technology, Fakulty of Computer Science and Automation, Databases and Information Systems Group
- Dr. Ingolf VOIGT *(since 01 July 2017)*, Deputy Managing Director, Fraunhofer Institute for Ceramic Technologies and Systems IKTS, Hermsdorf

[+] to 31 May 2017 / [++] since 01 June 2017

- **Chairman:** Dr.-Ing. Gabriel Kittler, X-FAB Semiconductor Foundries AG Erfurt, Innovation Manager
- **Assistant Chairman** *(to 31 March 2017)*: Olaf Mollenhauer, Kompass GmbH Ilmenau, Associate
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- Dr. Alfred Hansel *(since 1 April 2017)*, Managing Director Oncgnostics GmbH
- Univ.-Prof. Dr.-Ing. habil. Martin Hoffmann *(since 1 April 2017)*, Ruhr University Bochum, Faculty of Electrical Engineering and Information Technology, Chair of Microsystems Technology
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- Prof. Dr. Mario Kupnik *(since 1 April 2017)*, Darmstadt University of Technology, Faculty of Electrical Engineering and Information Technology, Measurement and Sensor Technology Group
- Dr. Peter Miethe *(since 1 April 2017)*, Managing Direkctor fzmb GmbH Research Centre for Medical Technology and Biotechnology
- Prof. Dr. Wolfgang Nebel *(since 1 April 2017)*, Oldenburg University, Fakulty II, Dep. of Computing Science, Embedded Hardware/Software Systems Group, and Chairman of the Board of OFFIS e.V.
- Prof. Dr. Ulf Schlichtmann *(since 1 April 2017)*, München University of Technology, Faculty of Electrical Engineering and Information Technology, Chair of design automation
- Dr. Peter Schneider, IIS Fraunhofer Institute for Integrated Circuits, Managing Director EAS Design Automation Branch Lab Dresden
- Prof. Dr. Ansgar Trächtler, University of Paderborn, Heinz Nixdorf Institute, Chair of Control Engineering and Mechatronics
- Prof. Dr. rer. nat. habil. Andreas Tünnermann *(to 31 March 2017)*, Director of the Fraunhofer Institute for Applied Optics and Precision Engineering IOF Jena and of the Institute of Applied Physics of the Friedrich Schiller University Jena
- Jörg Wende *(since 1 April 2017)*, Consultant Hybrid-Integration and Industry 4.0, IBM Deutschland GmbH Dresden

Lectures, lecture series

Prof. Dr. Ralf Sommer

at Ilmenau University of Technology, Department Electronic Circuits and Systems:

- Grundlagen der analogen Schaltungstechnik, lecture and tutorial, BSc 3rd sem.
- Rechnergestützte Schaltungssimulation und deren Algorithmen (EDA), lecture and tutorial, BSc, MSc
- Modellierung und Simulation analoger Systeme, lecture and tutorial, BSc

Prof. Dr. Hannes Töpfer

at Ilmenau University of Technology, Department of Advanced Electromagnetics:

- Theoretische Elektrotechnik I und II, lecture, BSc 4th/5th sem.
- Grundlagen der Modellierung und Simulation, lecture & tutorial, BSc 5th/6th sem.
- Schaltungen der Quanteninformationsverarbeitung, lecture, MSc 2nd sem.
- Elektromagnetische Sensorik, lecture, MSc 2nd sem.
- Technische Elektrodynamik, lecture, MSc 2nd sem.
- Supraleitung in der Informationstechnik, lecture, MSc 1st sem.
- Project seminar ATET, lecture, MSc 2nd sem.

Events

Workshops / IMMS as Host

Sensorik-4.0-Tag (Sensors 4.0 Day), workshop & regulars' table, 18 May 2017, IMMS Ilmenau *(lectures, organisation)*

5th RIS3 Forum, Regional innovation strategy for intelligent specialisation, 15 Jun 2017, Ilmenau TU *(guided tour at IMMS Ilmenau)*

2nd edaBarCamp, Workshop, 05 – 06 Jul 2017, Robert-Bosch-Zentrum Reutlingen *(IMMS as initiator and co-organiser)*

2nd Stammtisch Sensorik 4.0 (Regulars' Table Sensors 4.0), 17 Aug 2017, IMMS Ilmenau *(lecture, organisation)*

2nd Workshop Sensorik 4.0, 25 Aug 2017, IMMS Ilmenau *(lecture, organisation)*

Lange Nacht der Wissenschaften (Long Night of Sciences) 03 Nov 2017, IMMS Erfurt *(demonstrations, live demos, lectures)*

3rd Stammtisch Sensorik 4.0, 09 Nov 2017, IMMS Ilmenau *(lecture, organisation)*

3rd Workshop Sensorik 4.0, 23 Nov 2017, IMMS Ilmenau *(lecture, organisation)*

Current events at www.imms.de.

3rd edaBarCamp – the next generation! Workshop, 11 Dec 2017, Leibniz University Hannover *(IMMS as initiator and co-organiser)*

Trade fairs/Exhibitions

JeTT 2017 Jena Science Day, 31 Jan 2017, EAH University of Applied Sciences Jena *(IMMS as exhibitor)*

Mittelstand 4.0 – Kompetenzzentrum Ilmenau (SME 4.0 – Competence Centre), inaugural event, 17 Mar 2017, Ilmenau TU *(demonstrator; IMMS as co-exhibitor)*

EBS 2017 First European/10th German BioSensor Symposium, 20 – 23 Mar 2017, Potsdam University *(IMMS as co-exhibitor, joint booth DiagnostikNet BB)*

2nd Thüringer IT-Leistungsschau (IT expo), 06 Apr 2017, Jena *(IMMS as co-exhibitor)*

Innovationstag Mittelstand 2017 (SME innovation day), 18 May 2017 , AiF The German Federation of Industrial Research Associations Berlin *(demonstrator)*

MEDICA 2017, 13 – 16 Nov 2017, Messe Düsseldorf *(live demo; IMMS as co-exhibitor joint booth DiagnostikNet BB)*

Publications

Conferences with contributions by IMMS – an overview

Silicon Saxony AK CPS, Working Group Cyber-physical Systems, 01 Feb 2017, Dresden TU *(lecture)*

AWF, Working group for economic production, 13 Feb 2017, Ilmenau TU *(lecture)*

1st IID /3rd RIS3 Forum, 1st Industry Innovation Dialogue / 3rd Forum Regional Innovation Strategy for Intelligent Specialisation "Production monitoring and control", 15 Feb 2017, Ilmenau TU *(2 lectures)*

ANALOG 2017, Workshop, 02 – 03 Mar 2017, Berlin TU *(lecture)*

TuZ 2017, 29th GMM/GI/ITG Workshop – Test methods and reliability of circuits, 05 – 07 Mar 2017, Lübeck *(lecture)*

SCI 2017, 14th Int. Conference on Sensors, Circuits and Instrumentation Systems, 28 – 31 Mar 2017, Marrakesh University, Morocco *(lecture)*

11th ITG-Fachtagung, Conference on Broadband Supply in Germany of the VDE Information Technology Society, 29 – 30 Mar 2017, Fraunhofer HHI Berlin *(lecture)*

Digitale Gesellschaft/Politisches Bildungsforum Thüringen (Political Education Forum on Digital Society), 04 Apr 2017, IPOL Institute Ilmenau *(lecture)*

DDECS 2017, IEEE International Symposium on Design and Diagnostics of Electronic Circuits and Systems, 19 – 21 Apr 2017, Dresden *(co-author, lecture)*

Current events at www.imms.de.

edaWorkshop 2017, Workshop on Electronic Design Automation, 08 – 10 May 2017, Dresden *(2 lectures)*

NOVEM IT Congress, 10 May 2017, Novem Car Interior Design GmbH Vorbach *(lecture)*

Weimarer Wirtschaftsforum (Weimar Economic Forum), 22 May 2017 *(lecture)*

CDNLive EMEA 2017, European Cadence User Conference, 15 – 17 May 2017, München *(lecture)*

EHW Oulu 2017, The 4th Workshop in Devices, Materials and Structures for Energy Harvesting and Storage, 17 – 18 May 2017, Oulu University, Finland *(lecture)*

Sensorica 2017, IEEE Workshop, 08 – 09 Jun 2017 – Hochschule Ruhr West, Mülheim an der Ruhr *(3 lectures)*

SMACD 2017, 14th International Conference on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design, 12 – 15 Jun 2017, Taormina, Italy *(2 lectures, Competition Runner Up)*

1st Waltershäuser Technologietag (Technology Day), 13 Jun 2017 *(lecture)*

MedTech Summit, 21 – 22 Jun 2017 Nürnberg Messe *(lecture)*

elmug4future 2017, Technology Conference, Electronic Measurement and Instrument Technology Thüringen, 27 – 28 Jun 2017, Friedrichroda *(IMMS as co-exhibitor)*

Digitalisierungslösungen für den Mittelstand, Workshop on digitisation for SME, SME 4.0 – Competence Centre Ilmenau, 28 Jun 2017, Friedrichroda *(lecture)*

HiTEN 2017, International Conference and Exhibition on High Temperature Electronics Network 10 – 12 Jul 2017, Queens' College Cambridge, UK *(lecture)*

ISTET 2017, XIX International Symposium on Theoretical Electrical Engineering, 16 – 19 Jul 2017, Ilmenau TU *(specialist poster)*

FAC 2017, Frontiers in Analog CAD, 21 – 22 Jul 2017, Goethe University Frankfurt am Main *(lecture)*

FGSN 2017, 16th GI/ITG KuVS, expert discussion "Sensor Networks", Communication and Distributed Systems Division, Society for Computer Science/Information Technology Society, 07 – 08 Sep 2017, Hamburg University of Applied Sciences *(lecture)*

ISC 2017, 59th Ilmenau Scientific Colloquium, 11 – 15 Sep 2017, TU Ilmenau *(2 lectures)*

IEEE RFID-TA 2017, 8th Annual IEEE International Conference on RFID Technology and Applications 20 – 22 Sep 2017, Warsaw, Poland *(lecture)*

Jenaer Maschinensicherheitssymposium des TÜV Thüringen e.V. (machine safety symposium, Thüringen Technical Inpspection Agency), 27 Sep 2017, Jena *(lecture)*

M2M Summit 2017, 6th M2M Alliance Academic Day, 11 Oct 2017, Köln *(lecture)*

CHANTS 2017, 12th Workshop on Challenged Networks, 16 Oct 2017, Snowbird, Utah, USA *(2 specialist posters)*

Current events at www.imms.de.

Rohrer Dialog der Mittelstandsvereinigung pro Südthüringen e.V. (dialogue of the SME assosiation South Thüringen), 25 Oct 2017, Rohr *(lecture)*

TELFOR 2017, 25th Telecommunications Forum, 21 – 22 Nov 2017, Belgrade, Serbia *(2 lectures)*

RIS3 Jahresveranstaltung, Annual RIS 3 event Regional Innovation Strategy for Intelligent Specialisation, 28 Nov 2017, Erfurt *(lecture, poster)*

Kölner Industrietage 2017 des Arbeitskreises Produktionstechnik (Köln Industry Days of the Working Group Production Technology) 28 – 29 Nov 2017, Köln *(lecture)*

Informationstag Digitalisierung in der Elektroindustrie, information day on digitisation in the electrical industry for representatives of the German Electrical and Electronic Manufacturers' Association (ZVEI), 30 Nov 2017, SME 4.0 Competence Centre/ TU Ilmenau *(lecture with demonstrator)*

Reviewed Publications

Towards Robust Communication-Based Object Monitoring Under Harsh Propagation Conditions, Frank Senf[1]. Bojana Nikoli[3]. Bojan Dimitrijevi[3]. Silvia Krug[1]. Tino Hutschenreuther[1]. Hannes Toepfer[2]. *TELFOR 2017, 25th Telecommunications Forum, Belgrade, Serbia, 21-22 November 2017, pp. 1-4,* **DOI: https://doi.org/10.1109/TELFOR.2017.8249338.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [2]Ilmenau University of Technology. [3]University of Niš, Faculty of Electronic Engineering, Aleksandra Medvedeva 14, 18000 Niš, Serbia.

An Open Platform for Distributed Urban Noise Monitoring, Marco Goetze[1]. Rolf Peukert[1]. Tino Hutschenreuther[1]. Hannes Toepfer[2]. *TELFOR 2017, 25th Telecommunication Forum, 21-22 November 2017, Belgrade, Serbia, pp. 1-4,* **DOI: https://doi.org/10.1109/TELFOR.2017.8249339.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [2]Ilmenau University of Technology.

Testing Electrostatic Energy Harvesters: A New Topology for Accurate Characterization, Björn Bieske[1]. Gerrit Kropp[1]. Alexander Rolapp[1]. *SSD 2017, 14th International Multi-Conference on Systems, Signals & Devices, Marrakech, Morocco, 28-31 March 2017, pp. 331-336.* **DOI: https://doi.org/10.1109/SSD.2017.8166930.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Publications for other years at www.imms.de.

Sensor Technologien 2022, Autorenkollektiv: Prof. Dr. Karlheinz Bock. M. Eng. Paul-Gerald Dittrich. Dr. Klaus Ettrich. Prof. Dr. Thomas Fröhlich. Verena Graf. Dr. Volker Großer. Dipl.-Ing. Frank Hänschke. Dr. Hans-Dieter Hartmann. Prof. Dr. Dietrich Hofmann. Prof. Dr. Klaus-Peter Hoffmann. Prof. Dr. Thomas Ortlepp. Prof. Dr. Franz Schmidt. Prof. Dr. Andreas Schütze. Dr. C. Thomas Simmons. Dr. Wolfgang Sinn. Dr. Rolf Slatter. Prof. Dr. Hannes Töpfer[1,2]. Dr. Guido Tschulena. Prof. Dr. Roland Werthschützky. Prof. Dr. Jürgen Wilde. Dr. Gabriel Zieger. *Eine Studie des AMA Verbandes für Sensorik und Messtechnik e.V., Herausgeber Prof. Dr. Roland Werthschützky, 23. November 2017.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany. [2]Department of Advanced Electromagnetics, Ilmenau University of Technology, Germany.

Knowing your A/MS system's Limit: System Acceptance Region Exploration by using Automated Model Refinement and Accelerated Simulation, Georg Gläser[1]. Hyun-Sek Lukas Lee[2]. Markus Olbrich[2]. Erich Barke[2]. *In: Fummi F., Wille R. (eds) Languages, Design Methods, and Tools for Electronic System Design. Lecture Notes in Electrical Engineering, vol 454. Springer, Cham, 2017,* **DOI: https://doi.org/10.1007/978-3-319-62920-9_1.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [2]Institute of Microelectronic Systems, Leibniz Universität Hannover, Germany.

Supply sensitivity analysis for low-power time-domain temperature sensor in RFID application, Jun Tan[1]. Georg Gläser[1]. *RFID-TA 2017, IEEE International Conference on RFID Technology & Application, Warsaw, Poland, 20-22 September 2017, pp. 196-201.* **DOI: https://doi.org/10.1109/RFID-TA.2017.8098882.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Parasitic Symmetry at a Glance: Uncovering Mixed-Signal Layout Constraints, Georg Gläser[1]. Benjamin Saft[1]. Ralf Sommer[1]. *FAC 2017, Frontiers in Analog CAD, Frankfurt on the Main, Germany, 21-22 July 2017, pp. 1-6.* **URL: http://ieeexplore.ieee.org/document/8011279/.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Automated Generation of System-Level AMS Operating Condition Checks: Your Model's Insurance Policy, Georg Gläser[1]. Martin Grabmann[1]. Gerrit Kropp[1]. Andreas Fürtig[2]. *SMACD 2017 14th International Conference on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design, Giardini Naxos,*

Publications for other years at www.imms.de.

12-15 June 2017, pp. 1-4. **DOI: https://doi.org/10.1109/SMACD.2017.7981567.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [2]Institute for Computer Science, Goethe Universität Frankfurt a. M., Germany.

Comparing Apples and Oranges: Evaluating Model-Coverage using Acceptance Regions, Martin GRABMANN[1]. Georg GLÄSER[1]. *SMACD 2017, 14th International Conference on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design, Giardini Naxos, 12-15 June 2017, pp. 1-4,* **DOI: https://doi.org/10.1109/SMACD.2017.7981566.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

A contribution towards model-based design of application-specific MEMS, Jenny KLAUS[1]. Eric SCHÄFER[1]. Roman PARIS[1]. Astrid FRANK[1]. Ralf SOMMER[1]. *In Integration, the VLSI Journal, Volume 58, 2017, Pages 454-462, ISSN 0167-9260,* **DOI: https://doi.org/10.1016/j.vlsi.2017.03.014.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Novel Metrics for Analog Mixed-Signal Coverage, Andreas FÜRTIG[1]. Georg GLÄSER[2]. Christoph GRIMM[3]. Lars HEDRICH[1]. Stefan HEINEN[6]. Hyun-Sek Lukas LEE[4]. Gregor NITSCHE[5]. Markus OLBRICH[4]. Carna RADOJICIC[3]. Fabian SPEICHER[6]. *DDECS 2017 IEEE 20th International Symposium on Design and Diagnostics of Electronic Circuits & Systems, Dresden, 19-21 April 2017, pp. 97-102,* **DOI: https://doi.org/10.1109/DDECS.2017.7934589.** [1]Institute for Computer Science, Goethe Universität Frankfurt a. M., Germany. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH Ilmenau, Germany. [3]Design of Cyber-Physical Systems, Kaiserslautern University of Technology, Germany. [4]Institute of Microelectronic Systems, Leibniz Universität Hannover, Germany. [5]OFFIS, Institute for Information Technology, Germany. [6]Chair of Integrated Analog Circuits, RWTH Aachen University, Germany.

Feasibility of Dual-polarized Antenna Arrays for GNSS Receivers at Low Elevations, Maysam IBRAHEAM[1]. Bjoern BIESKE[2]. Kurt BLAU[1]. Eric SCHÄFER[2]. André JÄGER[2]. Safwat Irteza BUTT[3]. Ralf STEPHAN[1]. Matthias A. HEIN[1]. *EUCAP 2017 11th European Conference on Antennas and Propagation, Paris, 19-24 March 2017, pp. 857-861.* **DOI: https://doi.org/10.23919/EuCAP.2017.7928441.** [1]Thuringian Center of Innovation in Mobility, RF and Microwave Research Laboratory, Technische Universität Ilmenau, Germany. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [3]Robert Bosch GmbH, Stuttgart, Germany.

Publications for other years at www.imms.de.

Enhancement- and depletion-mode AlGaN/GaN HEMTs on 3C-SiC(111)/Si(111) pseudosubstrates, Wael JATAL[1]. Uwe BAUMANN[2]. Heiko O. JACOBS[1]. Frank SCHWIERZ[3]. Jörg PEZOLDT[1]. *Phys. Status Solidi A 214, No. 4, 1600415 (2017).* **DOI: https://dx.doi.org/10.1002/pssa.201600415.** [1]FG Nanotechnologie, Institut für Mikro- und Nanotechnologien MacroNano® und Institut für Mikro- und Nanoelektronik, TU Ilmenau, Postfach 100565, 98684 Ilmenau, Germany. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [3]FG Festkörperelektronik, Institut für Mikro- und Nanotechnologien MacroNano® und Institut für Mikro- und Nanoelektronik, TU Ilmenau, Postfach 100565, 98684 Ilmenau, Germany.

Latency Critical IoT Applications in 5G: Perspective on the Design of Radio Interface and Network Architecture, Philipp SCHULZ[1]. Maximillian MATTHÉ[1]. Henrik KLESSIG[1]. Gerhard FETTWEIS[1]. Meryem SIMSEK[2]. Junaid ANSARI[3]. Shehzad Ali ASHRAF[3]. Björn ALMEROTH[4]. Jens VOIGT[5]. Ines RIEDEL[5]. Andre PUSCHMANN[6]. Andreas MITSCHELE-THIEL[6]. Michael MÜLLER[7]. Thomas ELSTE[8]. Marcus WINDISCH[9]. *in IEEE Communications Magazine, vol. 55, no. 2, pages 70-78, February 2017,* **DOI: https://doi.org/10.1109/MCOM.2017.1600435CM.** [1]Technical University Dresden, Vodafone Chair Mobile Communications Systems. [2]Technical University Dresden, Electrical engineering and information technology. [3]Ericsson, Research. [4]RadioOpt GmbH. [5]Actix GmbH, R&D. [6]Technische Universität Ilmenau, Integrated Communication Systems Group. [7]IVM gGmbH, Communication and ITS. [8]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [9]Freedelity GmbH, Research and Development.

Publications in journals

Wie Mikroelektronik dabei hilft, Krebs im Frühstadium zu erkennen, Alexander HOFMANN[1]. Michael MEISTER[1]. Friedrich SCHOLZ[2]. Balázs NÉMETH[1]. Susette GERMER[1]. Hendrik HÄRTER[3]. *Elektronikpraxis, Fachwissen für Elektronik Professionals,* **online: https://www.elektronikpraxis.vogel.de/wie-mikroelektronik-dabei-hilft-krebs-im-fruehstadium-zu-erkennen-a-673280/.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [2]Senova Gesellschaft für Biowissenschaft und Technik mbH. [3]Elektronikpraxis, Redakteur.

Publications for other years at www.imms.de.

Anknüpfungspunkte für das Clusterforschungsprojekt ANCONA – Ideen der Projektpartner zur Überführung in die industrielle Anwendung, Georg GLÄSER[1]. Andreas FÜRTIG2. Markus OLBRICH[3]. Gregor NITSCHE[4]. Fabian SPEICHER[5]. Christoph GRIMM[6]. *Newsletter edacentrum 01/02 2017, 2. Dezember 2017.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. 2Institute for Computer Science, Goethe Universität Frankfurt a. M., Germany. 3Institute of Microelectronic Systems, Leibniz Universität Hannover, Germany. 4OFFIS, Institute for Information Technology, Germany. 5Chair of Integrated Analog Circuits, RWTH Aachen University, Germany. 6Design of Cyber-Physical Systems, Kaiserslautern University of Technology, Germany.

Presentations and Posters

INSPECT – Mikroelektronische Diagnostikplattformen für die personalisierte Krebsforschung und Mikro-Bioreaktoren, Autorenkollektiv[1,2,3,4,5]. *RIS3 Jahresveranstaltung, Session 3, Innovationsfelder „IKT, innovative und produktionsnahe Dienstleistungen" und „Gesundes Leben und Gesundheitswirtschaft", 28. September 2017, Erfurt.* [1]CDA GmbH. [2]iba Institut für Bioprozess- und Analysemesstechnik e.V.. [3]Senova Gesellschaft für Biowissenschaft und Technik mbH. [4]X-FAB Semiconductor Foundries AG. 5IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

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DFAM

AiF Forschungsnetzwerk Mittelstand

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DLR Project Management Agency

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EFRE EUROPE FOR THURINGIA EUROPEAN REGIONAL DEVELOPMENT FUND | EUROPEAN UNION

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ESF EUROPE FOR THURINGIA EUROPEAN SOCIAL FUND | EUROPEAN UNION European Social Fund

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DFG Deutsche Forschungsgemeinschaft

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DFG Deutsche Forschungsgemeinschaft

Abbreviations

5G *fifth generation mobile radio standard*

6LoWPAN *IPv6 over low power wireless personal area network; communication protocol for radio data transmission*

ASIC *application-specific integrated circuit*

BMBF *German Federal Ministry of Education and Research*

BMWi *German Federal Ministry of Economic Affairs and Energy*

CMOS *complementary metal–oxide semiconductor*

CP(P)S *cyber-physical (production) system*

DFG *German Research Foundation*

EDA *electronic design automation*

EFRE *European Regional Development Fund*

ESF *European Social Fund*

FTE *full-time equivalent*

HF *high frequency*

IC *integrated circuit*

IEEE *Institute of Electrical and Electronics Engineers; worldwide professional association of engineers*

IP *intellectual property; e.g. ready-made function block of an ASIC design*

IPv6 *internet protocol version 6; standardised method for data transmission in packet-switched computer networks (internet)*

LDO *low drop-out; low-drop voltage regulator for low voltage differences*

MCU *microcontroller unit*

MEMS *micro-electro-mechanical system*

NFC *near field communication; standard for near-field data transmission based on RFID*

OPC UA *open platform communications unified architecture; industrial protocol for communication between machines*

PID *proportional integral differential characteristic*

PMU *power management unit*

PWM *pulse width modulation; the information about the transmitted value is coded in the duty cycle of a digital signal*

RFID *radio-frequency identification*

RMS *root mean square; mean value of the standard deviation*

SME *small and medium-sized enterprises*

SoC *system-on-chip; complex ASIC with many different system components, such as micro-controllers, sensors, actuators, etc.*

TDC *time-to-digital converter; electronic module for measurement of short time intervals and conversion into a digital output*

TSN *time-sensitive networking; standards for transmission with very low transmission latency and high availability*

TU *technical university*

ULP *ultra-low-power*

WSN *wireless sensor network*

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