IMMS

ANNUAL REPORT

2016

Contents

Frontispiece: *Microelectronics (centre) developed by IMMS for use in early experiments on cancer diagnosis. Please go to the INSPECT report for details. Photographs and composition: IMMS.*

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

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

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Foreword

Thank you for your interest in IMMS. As in previous years, our Institute has been intensely active in 2016, helping our partners by bridging the gap between the first idea and a new application – both for them and with them. There was living proof in the work physically presented at the Institute's 20th birthday celebration: 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, Smart Mobility, the Digital Society, and Personalised Medicine) 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.

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...example: the "20 years of IMMS" chapter...

... or to access more detail.

We are pleased with our 2016 achievements. Reports on our scientific work at two leading international conferences shone in the Best Paper awards. 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.

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

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. Our thanks go, too, to the Ilmenau University of Technology for superb cooperation, which constantly enriches our work, and, more than that, brings such close research collaboration that synergy effects are felt in both establishments right across the boundaries between disciplines. Thank you all – sponsors, business partners, friends and every person bearing us up in our endeavours.

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

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

Prof. Dr.-Ing. Ralf Sommer	Dipl.-Ing. Hans-Joachim Kelm
Scientific Managing Director	Financial Managing Director

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Working hand in hand with the Technische Universität Ilmenau

Being an affiliated institute of Ilmenau University of Technology (TU), IMMS benefits from networking with the university while the TU benefits from the Institute's close relations with industry. The year 2016 saw IMMS working on shared research projects with 22 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

MUSIK research group*

Working closely with the Ilmenau TU RF and Microwave Research Laboratory and the departments of Micromechanical Systems and of Electronics Technology, 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. It is the intention that an entire system should be created from SiCer, an innovative material for such technology. For the purpose, IMMS has investigated and modelled the properties of MEMS in order to provide basic building blocks for universal design methodology. The aim is to achieve compact behavioural models complete with parameters for extended system simulation and optimisation.

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

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

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

systems with characteristics of independent intelligence, networking capacity and energy autonomy will be set up and validated in two demonstrators. For the purpose, research aspects of both microelectronics and mechatronics will be fused with those of computer science.

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.

KOSERNA research project*

2016 saw the conclusion of the KOSERNA research project. The outcome is a compact satellite signal receiver system supporting reliable navigation, for which IMMS developed the frontend circuit as a subcontractor to the RF and Microwave Research Laboratory. There is a detailed article on the subject in this annual report.

Mittelstand 4.0 centre of excellence*

The Ilmenau Mittelstand 4.0 centre of excellence under the leadership of Ilmenau TU provides support to SMEs in the introduction and initial use of the strategies relevant to introducing and using digitisation and Industry 4.0, which together with the electronic solutions are to be the means of bringing flexibility and optimum methodology into every process in the added-value chain and every stage of business through from the drawing board to manufacture in commercially-linked networks. The aim is to bundle the forces of the SMEs so that they can meet the growing demand for customer-specific products and services and so remain competitive. The IMMS contribution is, as Migration Fab, to stimulate Thüringen companies into gradual introduction of Industry 4.0 technologies.

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

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

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

This experimental setup for biological analyses was one of the IMMS stands during the ”Long Night of Technology“ on the Ilmenau TU campus, 28th May 2016.

Photograph: IMMS.

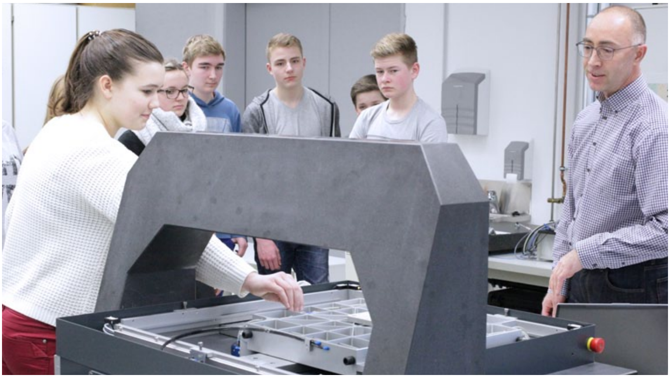
a whole, in the Basic Engineering School, a practically oriented outreach of the Technische Universität Ilmenau. With its opportunities for practical experiment in close conjunction with industry and with practical placements, guided tours and such keynote events as the Long Night of Technology (Lange Nacht der Technik) on the Ilmenau campus, IMMS contributes to student training and motivation. In September 2016, the 20-year anniversary of IMMS drew more than 40 student visitors, among them some young engineers from the DAAD programme for South America, and 60 school pupils. They witnessed live technical demonstrations in the formal ceremony and took up the opportunities of dialogue with exhibiting companies and the ZiB of Ilmenau TU. Here, they could collect information on possible subjects of study, suitable internships and career prospects.

In the Kinderuni (Children’s University), a yet younger generation received the attention of IMMS and the University. Professor Sommer gave a lecture entitled ”Images, Sounds, Numbers – What can my Smartphone do with them?“. He demonstrated to more than 600 children between 8 and 12 years old by means of interactive experiments how it is possible to describe and modify sounds and images simply with zeros and ones.

Research subjects for students at www.imms.de.

Encouragement of young academics – 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



A school pupils' visit to IMMS in March 2016.

This guided tour and other contributions by IMMS were part of the MINT[10] programme offered by the ZiB of Technische Universität Ilmenau.

Photograph: IMMS.

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 2016 saw 40 students being supervised at IMMS. Furthermore, there are eight IMMS researchers currently pursuing doctoral studies at various universities.

The fact that we have so high a proportion of students from Ilmenau University of Technology 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 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.

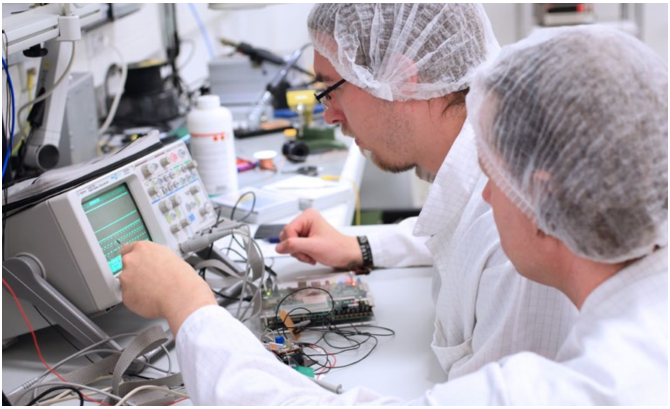
Supervised disciplines

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.

Research subjects for students at www.imms.de.

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



Here measurements are being taken in the (cleanroom) laboratory of the erfurt section of IMMS for a student dissertation on the design and construction of a readout system for a passive RFID microsensor array, supervised by the Institute.

Photograph: IMMS.

complex engineering tasks like developing a microelectronic circuit from schematic design through to production and measurement.

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.

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.

Voices of colleagues at www.imms.de.

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.

Research subjects for students at www.imms.de.

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.

More detail about infrastructure at www.imms.de.

Photograph: Reinhard Ferdinand (CC BY-SA 4.0, Beschnitt: IMMS).

Obituary.

We bid one of our founders farewell.

Prof. Dr.-Ing. habil. Prof. h.c.

Eberhard Kallenbach

*16. August 1935, † 19. Oktober 2016

With his restless, pioneering spirit and his unshakable optimism, Professor Kallenbach helped create IMMS. He remained the Institute's valued guide and advisor, going with us every step of the way and even into his old age giving us the benefit of all his expert knowledge as a member of the Scientific Advisory Board.

Professor Kallenbach held the first Chair in Mechatronics at the Technische Universität Ilmenau. He it was who laid the foundations of one of the pillars on which IMMS stands: the interdisciplinary analysis and understanding of a matter, followed by optimisation. His idea of mechatronics, the very embodiment of a concept by which engineers combine their disciplines, is still our guiding light at IMMS.

We shall miss him: we shall miss his huge personality and his humane, sincere and ever-helpful approach. We extend our heartfelt condolences to his family.

On behalf of everybody on the staff, Professor Ralf Sommer, Hans-Joachim Kelm (the managing directors) and on behalf of the Scientific Advisory Board, Dr. Gabriel Kittler.


20 YEARS
OF IMMS
20 Jahre IMMS
No Application
BS 10 (10040)
X-FAB expertise worldwide.
Ready for the X-FABulous Team?
Industrie 4.0

20 Years of IMMS. Lasting memories ...

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The day was 13th September, 2016. It celebrated 20 Years of IMMS. About 300 people came from industry, research, teaching, networks, project clusters, politics and the media. Besides the ceremonial gathering and colloquium in the Helmholtz lecture theatre of Ilmenau University of Technology, they attended the various guided tours, the exhibition and the networking events on the IMMS premises. Among the 300 were 26 speakers, 13 exhibitors, 41 students, 60 school pupils and 56 guided tour participants.

Colloquium

The morning colloquium was entitled ”We connect information technology to the real world“, and began with a keynote speech on the subject of digitisation by Dr. Johannes Eisenmenger of Carl Zeiss SMT GmbH. Then four specialist lectures were given on a selection of IMMS' current research themes. Speakers came from X-FAB, Senova, Melexis and SONOTEC and, paired with their IMMS research colleagues, explained the design of complex MEMS (micro-electro-mechanical systems); point-of-care diagnosis using microelectronics; reliability and quality in integrated sensor circuits; and leak detection in industrial processes using ultrasonics. The boundaries were explored between the fields of physics and engineering and between pure science and its applications.

There are videos of the lectures at www.imms.de.

▾ Keynote: Dr. Eisenmenger, Zeiss SMT.
Photographs: IMMS.

◂ X-FAB's live demo during the formal ceremony.

◂ Specialist lecture with live demo: Prof. Holstein, SONOTEC, and Dr. Hutschenreuther, IMMS.

Formal ceremony

There were welcoming words from Professor Peter Scharff, the Rector of the Ilmenau University of Technology, from Professor Dagmar Schipanski (who was a co-founder of IMMS) and from Gerd-Michael Seeber, Ilmenau's Mayor, in the formal ceremony in the afternoon. Then, the Minister gave his speech before slipping into a rather special jacket. This smart little number has electronically conducting threads knitted into it which in combination with washable electronics developed by IMMS form the prototype of a textile remote control system. It has now been submitted

There are videos of the formal ceremony at www.imms.de.

for patenting under the name Knitty-Fi. It is the wish of Dr. Gottfried Betz, the Managing Director of the Zella knitwear factory, to develop this system right through the mass production stage with IMMS.

Launch of the live demo: host Steffen Quasebarth (mdr), Minister Wolfrang Tiefensee (TMWWDG) and Prof. Dr. Ralf Sommer (IMMS). Photograph: IMMS.

Launch of the live demo

But now it was possible for Minister Tiefensee to use the jacket and and its integrated wireless switches to start off the live demo with the trip of a model train to three miniature railway stations. On arrival he took out of the trucks three scaled-down versions of projects developed at IMMS for the fields of Industry 4.0, biomedical sensors and IoT (the Internet of Things), getting Professor Ralf Sommer of IMMS to explain their highlights.

See the live demonstration: www.imms.de.

Developements at five-minute intervals

There followed a series of nine five-minute presentations in which partners of IMMS spoke of their joint developments. Many are already ripe for marketing and some already providing useful service in practice. Steffen Quasebarth, the host of the Thüringen Journal programme on MDR, chaired the proceedings and elicited explanations of the succession of innovations rapidly assembling on the birthday table: an optical implant to treat blindness, the planar positioning system of a nano 3D printer used in biological implantation, a smart current clamp used in checking industy and equipment, wireless sensor networks for exploring the environment

Supracon ▸ presented the terahertz scanner.

▴ Indu-Sol presented the smart current clamp in action.

◂ Tetra during the live demo of the drive for the nano 3D printer. Photographs: IMMS.

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and a USB programmer toolkit for highly efficient testing of chip production. The exhibits were shown in action by the various partners, live pictures and short videos of the many ways they are used were projected on the big screen.

Expo at IMMS.
Photographs: IMMS.

Expo and guided tours

These and other exhibits, for instance those extending the range of electric vehicles in town traffic, those providing quantitative early cancer diagnoses, the ultrasound device used in industry for preventive maintenance and many others, were on show to the visitors gathered at the Expo and on guided tours on the IMMS premises and in the Competence Centre Nanopositioning and Nanomeasuring Machines (CC NPMM). Many lively conversations ensued during the networking at IMMS. Questions evoked explanations, ideas were exchanged and new contacts established.

See a short film of the day at www.imms.de.

Prof. Dr. Erich Barke.

Citations

During the formal ceremony, Professor Erich **Barke**, erstwhile president of the Leibniz University, Hannover, spoke in his keynote address, "Keeping up with Complexity (Wettlauf mit der Komplexität)“, about means of reaching highly complex technical solutions and the significance of preparatory research which is geared to a particular application. He shed light on how important it is to transfer any success achieved in developing electronic design automation (EDA) in the field of microelectronics into other systems such as the micro-mechanical type – one of the research practices followed at IMMS. Professor Barke emphasised that it is in the design that the key to scientific and marketing success in complex smart digitised systems lies.

It was exactly this that Minister **Tiefensee**, speaking without notes, praised in the speech he gave as guest of honour. IMMS was founded 20 years ago to blaze this trail for Thüringen's industrial enterprises. This institute of the 'Land' of Thüringen had meanwhile brought the most up-to-date of research outcomes from microelectronics, mechatronics, IT and systems engineering within reach of the region's SMEs. In the period 1996 – 2016, the 'Land' had funded the Institute to the extent of more than 37 million euros. The Minister vouched for the efficacy of IMMS in continuing to support Thüringen's industry: addressing the challenges of the future in digitisation and life sciences. For that reason, the regional government would not cease to continue in its positive support of IMMS.

Lasting memories

Our guests' lasting memories are the many eureka moments – the illuminating solutions, the presentation of the state of the art in engineering research and development, the breadth of the work and collaboration, the interlocking of the various subjects, and the insight into the very DNA of IMMS, as so many of them indicated in their response to the day.

Guests at the formal ceremony. Photograph: IMMS.

The day also brought many interesting and productive conversations. Ideas were tossed about that might be input for future projects, new contacts were established and mutual aquaintances shared. We at IMMS were particularly delighted to find school pupils and university students getting into dialogue with our industrial partners. Lasting results are not restricted to the TV and radio feature, the 15 reports in the regional press and professional journals, the 12 contributions appearing on other websites, the many social media mentions given by our partners and the highest hit rate the IMMS website has experienced since its relaunch. Lasting results can also be found in the documentation. The lectures, speeches and glimpses of the day were recorded on film. IMMS has set up a YouTube channel, embedded the video files into www.imms.de, accompanied by links to scripts, photographs and relevant project content.

We hereby express our sincere thanks

As all of this would not have been possible without the commitment of our colleagues in the partner businesses, we hereby express our sincere thanks to all those partners and, indeed everybody who worked so hard to contribute to the success of the event. We also wish to thank the companies that made a donation to our charitable activities, the funding scholarships and grants to the next generation of scientists. For their highly competent support in video streaming and photography, our thanks go to the "Forschungsgemeinschaft elektronische Medien e.V." of Ilmenau University of Technology.

See a short film of the day at www.imms.de.

Dr. Gottfried Betz, Managing Director, Strick Zella GmbH & Co.KG. Photograph: Strick Zella.

Dr. Betz and Minister Tiefensee, TMWWDG, presented the development during IMMS' celebration of its 20-year anniversary. Photograph: IMMS.

See the live demonstration: www.imms.de.

Dr. Gottfried Betz, Strick Zella

„There is a great future for wearables. Textiles bend and breathe with the wearer and can be made up into many different garments. And if they have smart aspects, many new applications are opened up that were previously untapped by mere electronics in the traditional sense. But operability is often a problem and laundering rarely possible. For these reasons, we have developed a smart type of textile that is robust, washable and intuitive in use. A great variety of know-how in combination was necessary: cloth-making, electronics, radio engineering, software and design. Our company and others which are smaller could not have done this alone.

With the expertise of IMMS on board, we were able to launch an innovative combined solution which has meanwhile been registered for patent under the name of Knitty-Fi. It contains switches knitted in electrically conducted thread, electronic signal processing, a power supply and wireless communication. The switches will control devices such as machines that are up to 30 metres away.

Go to the Smart Jacket article.

IMMS did not only design, develop and integrate the electronics constantly taking account of additional specifications: more than that, IMMS initiated the idea of simply using a smart phone to configure the system, which is a persuasive selling point for potential customers. We have had our first enquiries, from the furniture industry, for instance. The next stage will be to proceed towards mass production. Here, again, we shall continue to build on the sound knowledge of IMMS and its holistic, highly-committed approach."

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

www.strick-zella.de

„Cancer is one of the most frequent causes of death in both Germany and the EU. Early diagnosis is essential for a successful cancer treatment. The aim of the joint research project called INSPECT* is the development of a point-of-care diagnostic platform that will recognise prostate cancer at an early stage. In the individualised cancer diagnostics immunological methods are used to detect analytes and to produce a concentration dependent signal by means of a transducer which correlates with the severity of the disease. Tiny sensors are required which pick up the smallest signal changes. These sensors must also be inexpensive and permit easy handling of the diagnostic device.

Dr. Friedrich Scholz,
Senova Gesellschaft für Biowissenschaft und Technik mbH,
Photograph: Senova.

All the above specifications are met by the microchips that have been developed by IMMS. They use an array of photodiodes for detection and multi-stage signal amplification for the perception of very small signal fluctuations. The chips developed by IMMS have been made capable of analysing the complex samples such as blood using special packaging technology combining them with tailor-made circuit boards and reaction vessels. Thus a point-of-care diagnostic system could be prototyped, allowing bio-medical analyses to be carried out at the premises of the Senova GmbH. Specific antibodies were deposited onto the surface of the microchips, transducers were developed suitable for the chip and they were integrated into the system.

Go to the INSPECT article.

HRP-based biochemical staining was produced in the sample fluid and on the sensor surface for the quantitative colorimetric measurements. The high resolution of the signals and the accurate signal detecion made it clear that simple, quick, reliable diagnosis and monitoring of certain cancers is possible. The system is currently being tested for prostate and colon cancer diagnostics. In the future the various sensors on the chip should allow the analysis of a range of parameters so that cancer diagnosis will become ever more reliable and certain and so that the monitoring of individual therapies will become possible.

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

IMMS demonstrated great commitment in responding to the huge challenges on the development of the point-of-care test and on the associated sensor specifications. The excellent cooperation between IMMS and ourselves is the foundation for the operational work in this interdisciplinary project.

Our experience demonstrates that IMMS application-oriented analyses, understands and models the biochemical processes. Furthermore, the colleagues implement the specifications with their integrated system design and are flexible in adapting the systems as necessary. The combination of the the competencies of the IMMS in electronics and signal acquisition with the experiences of Senova in developing diagnostic products provides a promising foundation for a further successful cooperation.“

www.senova.de

Tobias Baumgartner, Pepperl+Fuchs

„As specialists in electrical explosion protection and sensors for the automation of industrial buildings and processes, we supply customised systems that are used across the board from automotive factories to water processing plant. IMMS has developed a chip for us that we can install into our remote I/O systems. These are systems that transmit processed data from the safe or explosion hazardous areas by connecting binary and analog sensors and to a control system via a bus interface. The most frequent use of our products is in zones with explosion hazard in the petrochemical, gas, chemical and pharmaceutical industries but also in other harsh industrial environments.

Tobias Baumgartner, Development Engineer Process Automation, Product Group Remote Systems, Pepperl+Fuchs GmbH. Photograph: Pepperl+Fuchs GmbH.

We prepared the internal programming code for a previous circuit and passed it to IMMS. IMMS then checked the code, found an FPGA solution to provide verification, and worked from that to specify the additional requirements for the new communication control, following up with the design and supporting us during manufacture.

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

More on the IMMS ASIC development possibilities: www.imms.de/ASICs.

They characterised and tested the chip, then coordinated the construction of and bonding technology for the housing.

The systematic methods of IMMS in simulating the logic and steadily verifying all functions greatly contributed to the fact that we had an error-free chip in the very first iteration. It has been integrated into our mass-produced products since late 2016 and we are more than satisfied. We extend grateful thanks for the excellent cooperation and ready communication. It will be a pleasure for us if there is a future opportunity of joining forces again with IMMS in successful development.“

www.pepperl-fuchs.com

Dr. Dieter Treytnar, edacentrum

„IMMS is one of the ANCONA* partners (Analog-Coverage in Nano-Electronics), a project which is running from 2014 – 2017 and of which IMMS is a member. IMMS staff have made a significant contribution to the integration of the ANCONA results into the development processes of the industrial partners also involved in the project.

Dr. Dieter Treytnar, Project Manager, edacentrum GmbH, Hannover. Photograph: edacentrum.

More on the ANCONA project: www.imms.de.

Inspired by ANCONA, the idea came up of running an open, participatory researchers' session based on the concept of a chaired maxi-group. The idea became the edaBarCamp, a ”non-conference“. As its name suggests, it was to be the first BarCamp in the field of electronic design automation for microelectronic and embedded systems. It was organised by the edacentrum, IMMS and OFFIS.

The communications methods used in an event of this type are almost exclusively those of social media such as Facebook, XING, and Google Docs, all of them channels particularly preferred by youngest-generation researchers. Thanks to the support given by IMMS on organisation and content, the first edaBarCamp was so successful that everybody agreed to repeat it in future years as a series of events emanating from other places in Germany.

More detail abaout the edaBarCamp at www.imms.de.

We at the edacentrum are pleased with our cooperation to date, but above all delighted that the always excellent cooperation with IMMS is to continue.“

www.edacentrum.de

Michael Muth, AeroLas

Dipl.-Ing. Michael Muth, Managing Director, AeroLas GmbH, Unterhaching. Photograph: private source.

„At AeroLas, we have been pursuing a new R&D idea in the field of aerostatic guides in a joint project with IMMS and Ilmenau TU. The result of this highly successful cooperation has been a compact vertical drive element with integrated magnetic vertical actuator and reliance on compressed air, not electricity, for the weight compensation. This active guiding element means that the position in the vertical can be controlled with nanometre-precision while the load is being carried with virtually none of the power loss which might occasion problems due to warming. Elements like this are of particular interest for drive systems requiring perfect positioning and measurement on the nanometre scale, features that are necessary in display manufacture or optical measurement of reticles and wafers.

Go to the AFiA article.

We have for many years been appreciative of our cooperation with IMMS, their focused attitude to the work and their professionalism. The results from this project will be the basis of product design to the specification of future AeroLas customers. IMMS will likewise be an important partner for us in future developments because of its outstanding expertise in the field of magnetic drives.“

www.aerolas.de

More testimonials at www.imms.de.

Measuring energy needs with prototypes that monitor trains in the "fast realtime"* project; IMMS is ensuring low latency with a local wireless sensor network. Photograph: IMMS.

RESEARCH SUBJECT CPS:

ENERGY-EFFICIENT AND ENERGY-AUTONOMOUS CYBER-PHYSICAL SYSTEMS

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.

More on Industry 4.0 at www.imms.de.

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

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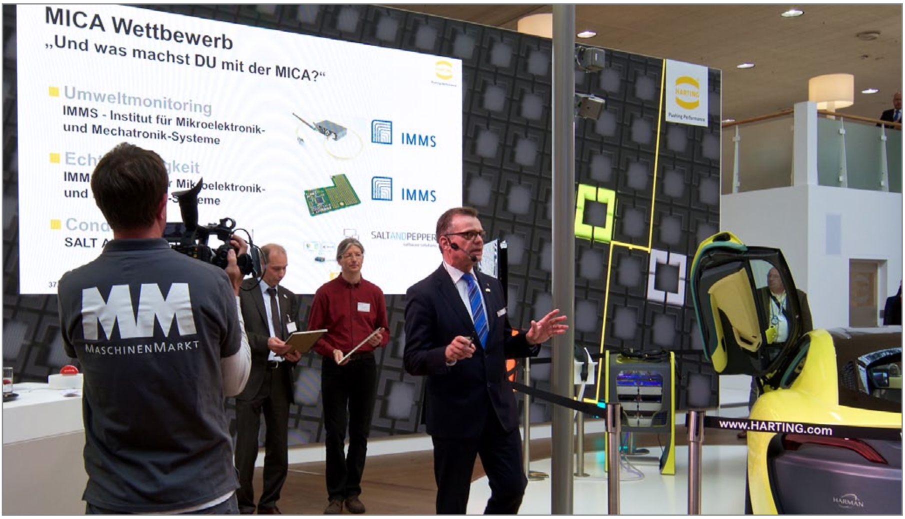

IMMS being awarded the MICA competition prize at the HARTING stand, Hanover Trade Fair, 2016. Photograph: IMMS.

Highlights of 2016 in our energy-efficient and energy-autonomous systems research

IMMS wins the HARTING MICA competition and joins the MICA network

IMMS achieved distinction in the ”What do you do with MICA?“ competition for two instances of development: in environmental monitoring and real-time data-processing. Both were presented live by two teams from IMMS at the Hanover Trade Fair in April 2016 and seen by a wide general and press audience.

The Institute had taken only a few weeks to create the innovative applications using the platform. HARTING's open-computing MICA (Modular Industry Computing Architecture) system can be extended and configured to the user's taste with application-specific hardware, software and interfaces. The company had run the competition to stimulate developers in sounding out MICA's possibilities across the broadest of fields. The submissions were evaluated on innovation, usefulness, practicability and creativity.

More detail abaout MICA at www.imms.de.

After this, in June 2016, IMMS was at the kickoff meeting of the newly founded MICA network in the Robotation Academy, Hanover. The Institute is going to play an active part in this network with other MICA users, producers and developers and among other benefits will link up its prize-winning solutions to other uses.

MICA as environmental monitoring solution

In applying MICA to the monitoring of ambient conditions, IMMS had combined the architecture with networked outdoor wireless sensors that were recording soil moisture, temperature and light and had also integrated it into IoT, the Internet of Things, so that there was complete data transfer from the sensor to cloud. MICA functions as data logger and IoT gateway, providing a web-based user interface.

IMMS extended the MICA platform with an IEEE-802.15.4 radio-transceiver functional circuit board to which wireless sensors can be coupled. In addition, the Institute implemented a scalable multi-container solution with cloud integration based on MQTT and used 6LoWPAN and IMMS BASe-Net technologies to forge the connections. The methodology is applicable not only to environmental measurement situtations but also, for example, to traffic monitoring or the field of the smart city and smart transport.

MICA for real-time applications

The second submission on the part of IMMS was a real-time solution that addressed one of the central demands that Industry 4.0 makes on MICA, which is the ever-increasing quantity of data generated by a huge number of distributed sensors. It is vital that this data be processed reliably and promptly, in real time: otherwise, there may be loss of quality or even industrial catastrophe.

This requirement led IMMS to optimise the MICA platform software, implement a real-time basic LINUX system, and analyse in detail the real-time performance achievable with MICA. This methodology can be adopted transparently into HARTING's software container concept. It is based not only on IMMS' long experience in the field but also on work done in the context of OSADL.

More detail abaout MICA at www.imms.de.

Project launch: platform to visualise, analyse and avoid an excess of urban noise*

Noise pollution diminishes quality of life. People living in conurbations are subject to assaults of many kinds from noise: sporting and other major events, building works or even individual moving vehicles. To improve their quality of life, a system is being developed in the "StadtLärm" (City Noise) project that enables 3D visualisation and processing of noise. This new application will assign the measured data to specific events, for instance to a down-town open-air concert.

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ZIM Zentrales Innovationsprogramm Mittelstand

IMMS is creating the basic software platform for a system that will visualise ”noise in space“ three-dimensionally and allocate the data measured and processed to specific events. Photograph: Beate Hövelmans, zwei de sign.

Benefit and overall concept

The program will improve the ability of local authorities to assess sources of noise. The acoustic and geographical data from past events will be predictive of future noise nuisance. The intention is to put the system to the test during the summer of 2018 in the town of Jena, Germany.

The data for the application will be supplied using a platform with noise sensors developed by Bischoff Elektronik GmbH and an MQTT broker acting as central turntable for messages among individual components in the system. This broker will be the interface for the evaluating algorithms provided by IDMT and for the StadtLärm application on which another of the project partners, Software Service John, is working, and in all probability for further services.

The IMMS contribution

IMMS is the partner creating the basic software platform for the noise sensors and data acquisition, also integrating the audio data which will have been prepared by IDMT. Responsiblity lies with IMMS for the communication via the broker and for defining the overall communications architecture including structures and messages, configuration and supervision of the broker and implementing a central administrative component for the system as a whole. Further, IMMS is integrating sensors for a variety of ambient conditions, to increase the usefulness of the platform.

The Best Paper Award went to IMMS at FDL 2016 for its new verification methods.

FPGAs (foreground) are used for the system simulation.

Photograph: IMMS.

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Best Paper Award for paper on computer-aided verification methods goes to IMMS

In September 2016, IMMS received the Best Paper Award at the Forum on Specification & Design Languages in Bremen for the paper "Knowing Your AMS System's Limits: System Acceptance Region Exploration by Using Automated Model Refinement and Accelerated Simulation".

More on the ANCONA project: www.imms.de.

Objectives

The paper described outcomes from the ANCONA* (Analog Coverage in Nanoelectronics), a cluster research project. There are another five universities or research establishments besides IMMS in the ANCONA cluster. IMMS is focussing on computer-aided verification methods which will improve the design of mixed (analog-and-digital) signal circuits, greatly accelerating it. It is through such circuits that the Internet of Things and Industry 4.0 will be put into practice. To date, it has largely been impossible to test in any setting but a laboratory the interaction between the system components and any of the parasitic currents arising (for example, from the mains voltage).

IMMS approach

For that reason, the project partners are working on computer-aided procedures that ensure reliable functioning of complex systems to be verified even at the design stage.

IMMS is at work on specialised methods of automatically extending models of mixed analogue-and-digital circuits at system level. This is firstly to establish regions of acceptance where the system is known to be reliable and secondly to identify critical scenarios. The ideas presented and honoured in Bremen were the subject of a full article in the IMMS annual report for 2015.

Go to the ANCONA report: www.imms.de.

Initial experiments on energy harvesting in the Green-ISAS project to supply energy to sensors in industrial plant. Photograph: IMMS.

Project start: the Green-ISAS* research group develops basic technologies for autonomous sensor-actuator systems for Industry 4.0

One key to unlock many Industry 4.0 applications is to be found in smart, autonomous sensor-actuator systems. The Green-ISAS project began in November 2016. In it, IMMS is developing a range of broadly applicable solutions in conjunction with Ilmenau TU.

Modules and methods

The basic modules will be yoked together to achieve highly efficient design, construction, testing and operation of new systems. To facilitate future development of useful application-specific technological solutions, Green-ISAS is already at work on design and test methods and the implementation of modular hardware and software components.

Demonstrators for validation

In new combinations, such systems with the characteristics of independent intelligence, networking capacity and energy autonomy will be set up and validated in two demonstrators. For the purpose, research aspects of both microelectronics and mechatronics will be fused with those of computer science. By taking a holistic view of the sensor-actuator systems and the interaction of their components, the researchers hope to overcome the technical barriers between individual elements of a system.

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

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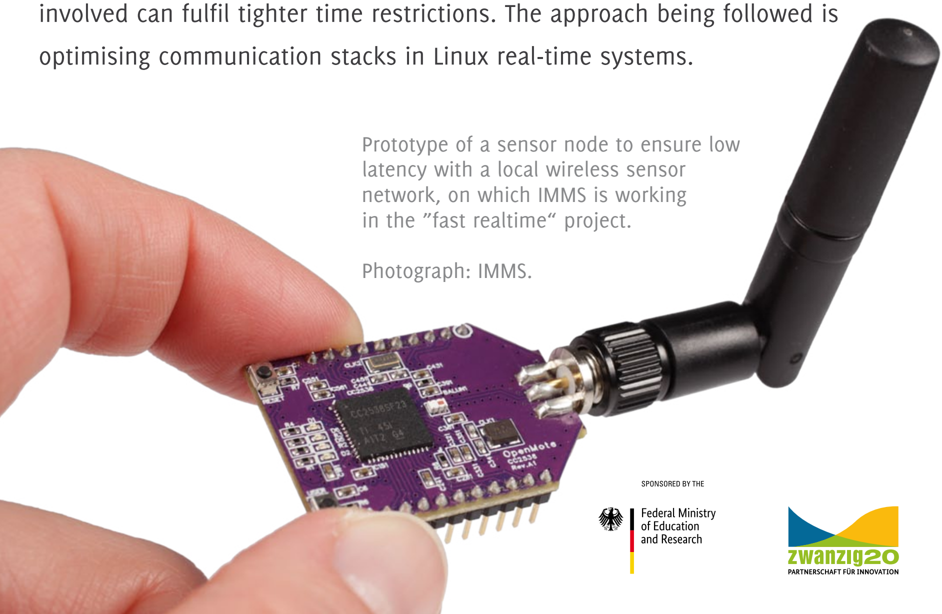
Specifically, the research is focussing on CMOS-based ultra low-power smart sensors, passive long-range UHF RFID frontends, design methods for optimal electromagnetic micro-energy harvesters, and the hardware and software to provide adaptive, distributed energy management in sensor-actuator systems.

Project begins on ”fast realtime“*: smart transport to be monitored in real time

There are nine project partners working on ”fast realtime“, tackling the basic principles and key technologies that will facilitate distributed sensor-actuator systems that work in real-time applications. This work will be the key to new developments, supporting, for instance, industrial automation and smart public transport. The nine partners are following a variety of routes to the real-time systems and are putting them into three demonstrator scenarios as examples of the variety possible.

One of these scenarios is the monitoring of the trucks on a goods train. For this setting, IMMS is developing a wireless sensor network that enables data to be received, processed and transmitted in real-time. In parallel, the Institute is at work on a contribution to the methodology in the form of general design guidelines for a new type of system design. Further, IMMS is developing a technological component which will minimise latency, as delay in data transmission is called, so that any systems involved can fulfil tighter time restrictions. The approach being followed is optimising communication stacks in Linux real-time systems.



Prototype of a sensor node to ensure low latency with a local wireless sensor network, on which IMMS is working in the ”fast realtime“ project.

Photograph: IMMS.

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„fast realtime": Communication stacks in Linux real-time systems

Especially in industry, there is currently a trend towards the use of Linux as the OS for systems working in real-time. In this field, data is usually output or read in a protocol stack, proceeding through various layers. For the TCP/IP Internet protocol, these are application, transport, Internet access and network access.

The buffering involved means that latency arises; latency is also caused by the ever-changing memory demands and possibly by the fact that several data streams are being processed in parallel. Such latency can impair the real-time capacity of the entire system.

IMMS is conducting research into ways of measuring the latency, characterising it and then eliminating any that is avoidable.

„fast realtime": Monitoring goods trains in real time

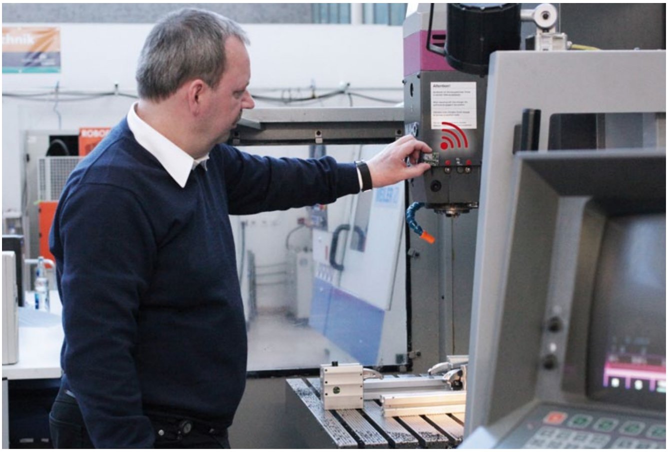
The use of sensors, location methods and status monitoring will, it is hoped, set a series of innovations in railway trucking in motion, for instance by enabling trains to find out for themselves the data that will give them clearance for their next route section. Currently, the information has to be gathered from the infrastructure along the line, with all that this means in terms of maintenance.

The networked systems integrated into the train will establish positions and journey times, check the train has all its trucks, permit automatic coupling of trucks and monitor the load and the wheels. The systems used for these purposes at present radio the data for each individual truck to an external central controller via mobile communications.

The "fast realtime" approach being investigated goes beyond this. The individual trucks are to be connected together under a monitoring application by means of a local wireless sensor network that requires no mobile communications.

It is the role of IMMS to create the prototype of the train's smart sensor network, which will then ceaselessly exchange data (bidirectionally, in a robust fashion, with low latency) between each truck and its neighbour the length of the train. The network will monitor the trucks and check all are present in the correct order.

For upstream use on the railway network, the train sensor network will be linked by a single mobile radio link to a location-related cloud service that has been optimised for the relevant signal transmission time, with the purpose of checking any changes and events also externally. This service can evaluate that information, if necessary triggering automatic measures.



Fitting wireless sensors as an extra is one way of helping to introduce Industry 4.0 technology.

Photograph: IMMS.

Mittelstand-Digital

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

IMMS playing a part in the Ilmenau Mittelstand 4.0 centre of excellence*

Since October 2016, IMMS has had a support role in the gradual introduction of Industry 4.0 technology to industrial companies in the region. To meet the growing demand for customer-specific products and services and so to remain competitive, small and medium-sized enterprises (SMEs) are having to optimise their processes and join forces. For this reason, the Ilmenau Mittelstand 4.0 centre of excellence has been set up to support to SMEs as they begin to apply the digitisation and other technologies needed in Industry 4.0. The electronic solutions are to be the means of bringing flexibility and optimum methodology into every process in the added-value chain and every stage of business through from the drawing board to manufacture in commercially-linked networks.

The German federal ministry for industry (BMWi) has funded the centre of excellence with Technische Universität Ilmenau at its head so that five partners, called Fabs, can offer relevant information and innovative approaches which are then put to the test. The Fabs, or ”Modellfabriken (model factories)“ bridge a number of fields, which include the networking of machines and production processes, the networking of 3D printing and individualised production, the generating of process data and data transfer, control and management of production, and data migration.

IMMS, now also known as the ”Migration Model Factory“, is supporting other enterprises in their gradual adoption of the technology applicable in Industry 4.0. An example of what this means is refitting machinery and equipment with wireless and networked sensors so that data can be obtained and processed to underpin new diagnostic, maintenance and service plans. Using universal electronics platforms for components that are Industry 4.0 compatible, together with open-source software, is an effective means of achieving rapid, reasonably priced, real-time innovation.

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

This desktop experimental setup with a breadboard was used to put the principles of the smart jacket to the test, particularly the control of the outside devices from the switch patches, and use of smartphone to configure. Photograph: IMMS.

Objectives and Overview

For almost everybody reading this, reaching for the remote will be obvious and automatic. But if one literally has one's hands full – or perhaps not when mobility is restricted by accident, illness, disability or the frailty of old age – even a little button can become a real barrier. If it were possible to control machines, lighting, furniture or games simply with a nudge of the arm against the back of an armchair or other solid object, those everyday barriers might fall. And in industry, for example, the control of machinery might be extended.

With these thoughts, Strick Zella GmbH & Co.KG, ITP GmbH Weimar and IMMS developed a potential solution: the prototype of smart clothing that one wears and can use as a remote control. The prototype is a jacket with three knitted switch patches in different colours. The "wool" in the two outside layers of the patch conducts electricity and there is a loosely knitted middle pad, see Fig. 1. This padding ensures the user can feel that switching is happening. It also controls the electrical contact. If the switch patch is compressed, the two conducting layers come into contact and the software

Figure 1:

Knitted switch patch made of conducting yarn and knitted spacer. Photograph: IMMS.

in the jacket processes the signal, which is then sent wirelessly to the intended receivers over a distance of up to 30 meters. The choice of receivers for the knitted switches can be preset using an app in a mobile phone. The item of clothing with all its functionality including battery can be washed at up to 60 °C and will work for up to three years without needing a battery change. There are no such systems as yet on the market.

The knitted switch patches, the wiring of the cloth, the cloth care requirements and the design of the jacket are all the responsibility of the knitwear factory, Strick Zella GmbH. Waterproof encapsulation of the electronics has been carried out by ITP GmbH. IMMS' role has been to design, create and integrate the energy-efficient electronics, selecting energy-saving components and optimising their interaction. In association with these tasks, the Institute has produced solutions for the power supply, radio link, and configuration by app as well as the provision of assured functionality. The outcome of all this work has been registered for patent as Knitty-Fi. It is the intention to work with IMMS towards mass production.

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

Details and IMMS' contribution

Solutions for the textile application

Distinguishing standby from operating under varying ambient conditions

IMMS carried out experiments on the extent to which the electrical resistance of the knitted patches would be affected by temperature and moisture both at rest and when pressed. This involved developing hardware and software to permit automatic triggering of the knitted switches during which the changes in resistance could be measured (see Fig. 2). The experimental setup enabled data to be gathered at five temperatures ranging from –20 °C to +50 °C and five levels of humidity between 0 %

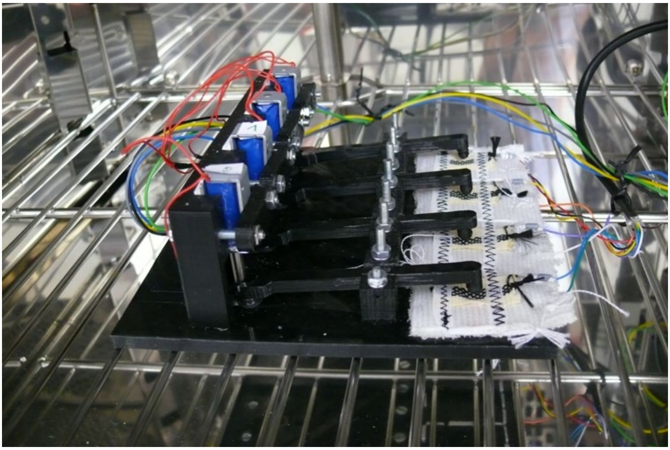


Figure 2:

This is the experimental setup in the climate chamber allowing automatic investigation of changes in resistance when cloth switch patches are activated under a variety of conditions.
The photograph shows the first version of the textile switches.

Photograph: IMMS.

and 80 % in a climatic chamber, for four times 100 actuations each. It was shown that the polymer yarn had very high resistance. The mean found on pressure was 15 kΩ; at rest, the figure was 500 MΩ. The results of the experiments produced a threshold of around 1 MΩ m at which it is possible to recognise the difference between the two states independently to climatic influences and material tolerances.

However, at around 100 % humidity, the difference in resistance was found to become insignificant, which implies that the switches will cease to function when wet.

Limiting parasitic errors in the circuit

In addition to climatic effects, the unshielded polymer yarn is directly subject to any outside electromagnetic interference. Addressing this, design strategies were found to limit the interference likely to affect the switches. They include insulating layers of material and capacitors at the input to the signal evaluation electronics which will suppress interference arising from skin contact with the wearer.

Bonding the yarn

As polymer yarn will not stand heat, it cannot be soldered or welded to the circuit board. The solution was to thread the yarn through fine holes in the board and knot it, then use conductive paint and the grout encapsulating the electronics to fixate it. The intention eventually is to use intermingling in the industrial manufacturing process to ensure contact with the board.

IMMS examined various versions of the textile switches, see Fig. 1 and Fig. 2, with varying electrical properties. In the course of the project, the electronics was being constantly adapted to the stage of development reached by Strick Zella GmbH.

Test measurements for the radio link

IMMS has selected IEEE 802.15.4 for energy-efficient radio communications. This standard enables solutions with very low power consumption and hence long battery life. It can also be used in the ISM bands for RF devices and will operate at the same time as other users of the bands, particularly by means of WLAN and Bluetooth.

There followed experiments on the radio link so that IMMS could identify the actual differences in range and packet loss in the two possible frequency bands (868 MHz and 2.4 GHz) for the product. Here, the experiments were on transmitters worn in the clothing, a receiver on a tripod at distances of 10 m, 20 m and 30 m, and varying orientations of the wearer's body in relation to the receiver, between 0° and 315° in 45° stages. A variety of antenna structures were tested on both transmitter and receiver. Fig. 3 shows that in certain constellations, packet loss may occur, which can however be compensated with a limited number of retransmissions, thus ensuring successful transmission of a switching command.

Each of the two bands was found to be suitable in principle to achieve a range in an unobstructed area of up to 30 m. The choice fell on the 2.4-GHz band because of the availability of radio modules with minimum standby current so that the system would be as energy-efficient as possible. The antennas for 2.4 GHz are, moreover, small. They can be easily integrated into clothing. Another advantage is that this frequency band can be used in all countries.

Figure 3:

- maximum NUMBER of repeats per packet for 99% of the measurements (0.99 quantile)
- arithmetic MEANS of the repeats per packet
- STANDARD DEVIATION of the repeats per packet

Distance \ Body orientation	0°	45°	90°	135°	180°	225°	270°	315°
30 m	0 0,00 0,04	0 0,01 0,10	0 0,03 0,68	0 0,00 0,00	0 0,00 0,00	0 0,00 0,00	0 0,00 0,06	0 0,01 0,12
20 m	0 0,00 0,00	0 0,00 0,00	0 0,00 0,00	0 0,00 0,00	0 0,00 0,00	0 0,00 0,00	0 0,00 0,00	0 0,00 0,00
10 m	0 0,00 0,00	1 0,03 0,30	0 0,00 0,00	0 0,00 0,00	0 0,00 0,04	0 0,00 0,00	0 0,00 0,00	0 0,00 0,00

Only very rarely was it necessary to repeat the data packet transmission during the experimental measurements. This sample of the statistics shows the repeats for a 2.4-GHz transmitter with chip sensor worn on the side of the body. 288 configurations in all were tested in 6 combinations of transmitter and sensor, 2 transmitter positions, 3 broadcasting distances and 8 body alignments. For each of the configurations, a data packet was sent every 100 ms over 60 s from a transmitter in the jacket to a receiver. On confirmation of reception, the data packet was always changed and a note made of the number of repeats necessary before transmission had succeeded. Source: IMMS.

Electronics to transmit switch commands

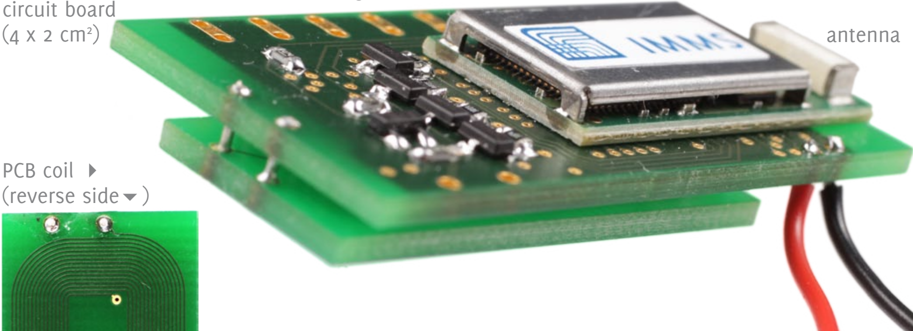
Taking into account the factors of radio protocol, energy consumption, interface and operating system, a radio module produced by Dresden Elektronik (deRFmega256-23M00) with an integrated transceiver was selected. To house the electronics, IMMS designed and created a circuit board with minimum dimensions and contact points for the polymer threads of four switch patches, see Fig. 4. The desired range of 30 meters between knitted patch and the object to be remotely controlled was possible to achieve with the standard chip antenna on the radio module; there was no need for adaptation.

Electronics for configuration by smartphone

To determine using an NFC[1]-capable smartphone which functions can be started from which switch, various PCB coils were designed for inclusion in the patch electronics. Commercially available coils were compared for inclusion on the board and a memory was selected. When measurements had been carried out to characterise the system and the range had been tested with an NFC reader, the best option for the NFC antenna in combination with the configuration electronics was put into practice and connected. The actuators were also fitted with the same type of coil to enable their assignments to switches to be configured. For wiring the knitted switch pads and connecting additional required sensors, the circuitry includes interfaces such as ADC and I²C.

1 *Near Field Communication, an international RFID transmission standard enabling data to be exchanged wirelessly across distances of a few centimetres.*

Figure. 4: Hardware developed at IMMS for the knitted remote control. Photograph: IMMS.



Washability

Both electronics and battery are specified for the temperature range from –40 °C to +85 °C. The encapsulation material and a polymer threads are corrosion-proof. For the washability of the entire system, this is absolutely essential. Mechanically, the system is protected by being enclosed in a pouch containing the flexible sealant and the electronics into which the polymer threads are sewn.

To ensure the washability of the garment and all of its components, project partner ITP GmbH developed a housing concept that encapsulates electronics and battery in two separate, interconnected chambers in a grouting process yielding a waterproof component. Repeated range tests carried out by IMMS using tripods at distances of 10, 20 and 30 metres with 1,000 packet transmissions each showed that the encapsulation did not cause any packet loss and that the signal quality was optimal on average.

Firmware and programming

TinyOS, a sensor network operating system, was ported onto the hardware selected to facilitate the development of firmware for communication and configuration. State-of-the-art communication schemes were surveyed before a radio protocol was developed and implemented at application level. This also supports a simple repeater function to improve communication in unfavourable circumstances and contains the actual control functions at the application level. To adequately protect the communication between garment and devices, the protocol was extended by cryptographic aspects. Besides integrity protections, these also offer protection against so-called replay attacks that would otherwise allow switching commands to be recorded and played back at a later time by potential attackers.

The software was made capable of parameterisation and an Android app was developed for its configuration so that functions could be assigned to the knitted patches from a smartphone. Additionally, garments and devices can be assigned separate networks identified by keys in order to enable larger-scale or overlapping deployments by different users.

Energy Management

Energy consumption measurements

As the first stage in selecting suitable batteries, the consumption of energy in various scenarios was estimated for the system. The energy measurements accompa-

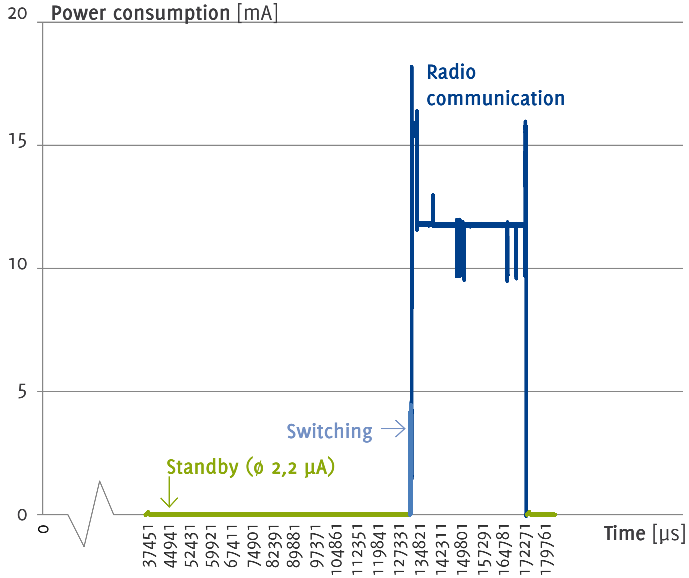


Figure 6:

One set of energy consumption measurements carried out for standby, switching and radio communication.

Power consumption was logged at 102.4 µs intervals, here plotted in milliampere.

Diagram: IMMS.

nied the development process and were carried out for the main operating phases: assignment of switches to devices, standby and switching followed by radio communication, see Fig. 6.

Assuming 60 switching events per day as originally specified and assuming that the switches are configured far less often than they are activated, the calculations show an excess of capacity in relation to the three-year desired lifetime for the batteries currently in use. This excess can be used, for example, to fit extra sensors.

Energy-efficient interaction between hardware and software

The long life achieved for the electronics is due to the choice of particularly economical hardware. A further advantage is that the operating system has been configured in such a way that the hardware will be energy-efficient in operation. IMMS has achieved this by designing circuitry and firmware in such a way that the radio module uses its energetically optimal state for each operating phase.

Assuming 60 switching actions per day, the overall system will be in deep-sleep mode most of the time, consuming about 2.2 µA. Only when a textile switch is pressed or the electronics is configured via NFC, the latter is awakened. After processing the event, electronics and receiver exchange packets in order to perform the desired switching action. After that, the system returns to deep sleep. This process takes no more than 100 ms currently. This means that the overall system will be active for only about six seconds per day.

Prototypes now exist of the system as described. The intention is to proceed to mass production and perhaps to develop further applications, which will necessitate, among other things, long-term testing under a variety of mechanical loads. The testing applies particularly to the method of connecting the conducting polymer threads with the electronics, this being critical to ensure robustness and secure operation. To date, the method is knotting, with fixation by electrically conductive paint and an encapsulating material. It would make sense to redesign the PCB with greater distances between the contacts for the threads, which would mean the whole patch and system would be more robust. For different applications, it would also be necessary to expand the work already done on recognition of moisture and the garment's being worn.

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The SmartJacket ZIM project is funded by the German Federal Ministry of Economic Affairs and Energy (BMWi) by resolution of the German Federal Parliament under the reference KF2534511CJ4 as a joint project in the ZIM scheme (a central innovation programme supporting SMEs).

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

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on the basis of a decision by the German Bundestag

ZIM Zentrales Innovationsprogramm Mittelstand

ENTOMATIC

Automatic monitoring of olive fruit flies

for more crop and less pesticide

Figure 1: McPhail trap in original form as basis of an automatic monitoring of olive fruit flies. Photograph: Nutesca S.L., Spain.

The Problem

Olive fruit flies, Bactrocera oleae, are the cause of crop loss in the olive plantations of Europe to the extent of around 600 euros per hectar. Across the 4.4 million hectars or so which are planted with olives in the EU,[1] these insects therefore cause destruction to the tune of perhaps 2.6 € billions, which represents about 30 % of all the olive gardens in the Mediterranean area, some of them actually annihilated.[2] The 2.5 million olive farmers affected by the economic damage represent about a third of all EU farmers.[3] EU policy for the olive oil market is to encourage production of high-quality oil for the benefit of producer, processor, trader and consumer. The costs of this policy run at about 2.3 € millions a year[4] but in no way serve to balance out the losses here described.

Details and video for the ENTOMATIC project at www.imms.de

The female Bactrocera oleae fly lays up to 400 eggs in several olives and, if temperature conditions are right, lives about 6 months.[5] Attempts at control cost about

1 *Data from the European Commission, Directorate-General for Agriculture (http://europa.eu.int/comm/agriculture)*
2 *Marshall Johnson, Olive Fruit Fly, Bactrocera oleae. Center for Invasive Species Research, University of California Riverside, 2010*
3 *IOOC, "Olive oil in the world market", OLIVAE No. 103, June 2005*
4 *International Olive Oil Council (2005). World Olive Oil Figures*
5 *Economopoulos AP, Giannakakis A, Tzanakakis ME, Voyadjoglou AV. 1971. Reproductive behavior and physiology of the olive fruit fly. 1. Anatomy of the adult rectum and odors emitted by adults. Annals of the Entomological Society of America 64: 1112-1116.*

€ 5,000,000 a year and basically take the form of ground traps and pesticide sprays.[6] The farmers' unions estimate perhaps a 30 % over-use of pesticide because it has to date been the practice only monitor the infestation by random sampling. Immense labour is involved in distributing traps across the olive gardens, often on rough terrain. To establish cases of critical frequency, the insects are counted manually at regular intervals. It is thus barely possible to get a prompt and accurate census. Neither can the best timing for counter-attack be precisely calculated. And so the farmers use excess pesticide prophylactically to protect their harvest, sadly overdosing both the crop and the environment.[7]

The Solution

The ENTOMATIC project has been able to develop a new automatic monitoring system. In future, it will enable critical concentrations of Bactrocera oleae to be counted rapidly and safely in the olive plantations. The trap type most often used in southern Europe is the McPhail trap. These are being equipped with sensors that reliably identify and quantify the fruit flies.

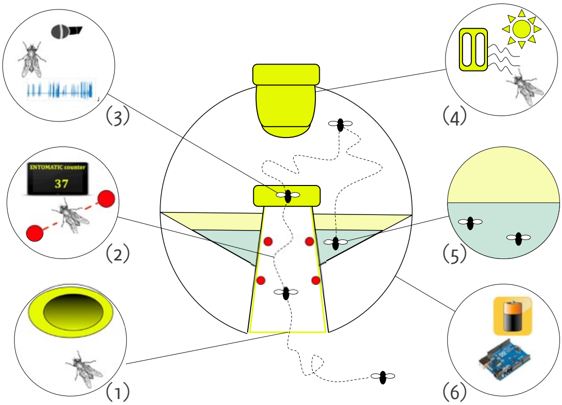

Figure 2: How the ENTOMATIC trap works.
Diagram: ENTOMATIC consortium.

The new ENTOMATIC McPhail trap is most suitable for experimental comparison with earlier versions and so is likely to find acceptance with users. The farmers' organisations have already had considerable experience with the conventional version.

The new version senses the Bactrocera oleae flying into it (1), in that at the point of entry (2) the insect is recognised by an opto-acoustic detector. Digital signal pro-

6 *A. Valavanidis,Th.Vlachogianni. Agricultural Pesticides Ecotoxilogical Studies and Environmental Risk Assessment. Department of Chemistry, University of Athens, University Campus Zografou, 15784 Athens, Greece, 2011.*

7 *Economopoulos A. P. (2002). The olive fruit fly, Bactrocera (Dacus) oleae (Gmelin) (Diptera: Tephritidae): Its importance and control; previous SIT research and pilot testing. Report to International Atomic Energym Agency (IAEA), Vienna, Austria; Michelakis S. (1990). The olive fruit fly, Dacus oleae (Gmel.) in Crete, Greece. Acta Horticulturae 286:371-374.*

Figure 3: Schematic diagram of the ENTOMATIC system. Diagram: ENTOMATIC Consortium.

cessing takes place and the system decides whether the insect is the olive fruit fly and of which sex (3). The bait in the trap ensures that the insects stay within the trap (4), and drown, just as they do in conventional McPhail traps (5). Attached to the top of the trap is electronic hardware containing the equipment for signal processing, detection of ambient conditions, power supply and networking of the traps (6). The data collected within the local network of traps in an olive plantation are transmitted together with exact GPS positions via smart wireless gateway to a CPU that contains the central management software.

At this central computer, the data on the current insect population and extent which come in are evaluated and visualised. In addition, it is possible in the same way to predict future developments and likely spread. As to the application of pesticides to keep the pests under control, the sheer amount of data enables optimum times and quantities to be calculated for each area of olive trees.

Further afield, the intention is sensor systems and hardware and software for data processing, communication and monitoring be used in such a way that different national systems may be networked, leading to a fully European early warning system.

The IMMS contribution has been to develop the specialised housing for the electronics and opto-electronic sensors which are used to count the fruit flies, unite the traps into a network with gateway and register ambient conditions. The casing is designed to protect the components against outside influences such as rain, dust and sunshine while at the same time offering easy access for maintenance jobs such as battery replacement. The McPhail has been adapted to accommodate the unit and the system with its electronic components has been integrated into the

Figure 4:

Trap prepared for 2017 field test.

The new trap contains the electronics and opto-electronic sensors which are used to count the fruit flies, unite the traps into a network with gateway and register ambient conditions.

Photograph: IMMS.

prototype. IMMS has also contributed to developing and fabricating the sensors and other electronics for the wireless networking of the traps and creation of the smart gateways. Another role of IMMS has been the assembly and initial installation of 25 ENTOMATIC McPhails for field tests. The prototypes modified with the sensors have been finalised by TEI Crete. The first field tests are to start in April 2017.

Details and video for the ENTOMATIC project at www.imms.de

Contact person: Dr.-Ing. Frank Spiller, frank.spiller@imms.de

The ENTOMATIC project is funded by the European Union under the reference FP7-SME-2013-605073 within the 7th Framework Programme of European Research, Technological Development and Demonstration.

IMMS is one of twelve project partners from Spain, Portugal, Greece, France, Belgium, Turkey and Germany.
Project website: https://entomatic.upf.edu

KOSERNA

Compact Satellite Receiver Systems for Robust Navigation Applications

Figure 1: Measurements being taken with the receiver, Ilmenau TU, September, 2016. Photograph: Dr.-Ing. Ralf Stephan, Ilmenau TU.

Objectives and overview

The transport of goods, the observation of public events, the measurement of buildings, the tasks and the inspection of agriculture – these are only a few of the ways in which mobile systems such as multicopters can be used. If these aerial systems are to be sent out to do their job without human intervention in situations where security and safety are critical, there will always be a need for navigation that is robust, absolutely accurate and proof against interruption or hacking: i.e., it can rely on features known in the trade as ”anti-collision“, ”anti-grounding“, ”geofencing“, ”coming home“ and ”autoland“. This is clear from the example of civilian UAVs (unmanned aerial vehicles). It is only by dint of spot-on, fail-safe navigation that a prescribed route can be followed so exactly that collisions are avoided, flying height kept within limits, no-fly zones avoided, and, in the event of a loss of communication, homing and automatic landing achieved – without any breach of the laws that apply.

For safety-critical autonomous navigation purposes, commonly and commercially available satnav equipment is out of the question for two reasons: potential breaks or errors in the positioning function, and susceptibility to interference. Satnavs receive their signals from satellites more than 20,000 kilometres away, which means those signals are very weak on arrival and that they are susceptible to the deliberate interference known as GNSS-jamming from transmitters able to send signals perhaps more than a hundred times their strength. Hijacking of the flying object itself is also a possibility.

For these reasons, as early as in the years 2010 – 2013, it fell to the German Aerospace Centre (DLR), the Ilmenau University of Technology, the RWTH Aachen and IMMS to research new designs, technology and algorithms for the sort of more compact adaptive group antennas necessary to eliminate satnav signal disruption. These are capable of fulfilling very high interference-mitigation specifications, but those developed so far were too large and heavy for actual mobile use. A receiving unit was designed by IMMS and partners which was only a quarter of the size of a conventional group antenna but had the same number of individual elements. It has proved the applicability of the signal treatment techniques. IMMS' part was to develop the receiver front end circuit forming the link between the antenna array and the digital evaluation software.

Details on the earlier project: www.imms.de

KOSERNA was started as a follow-on project in 2014. In it, the same partners have constructed an industrial prototype on the basis of the results achieved in 2013 in conjunction with the antenna engineering company Antennentechnik Bad Blankenburg GmbH. In parallel, the partners have worked on the issues of significantly increased accuracy and robustness for a novel receiver unit. For it, IMMS as subcontractor to Ilmenau TU (Technische Universität) has extended the frontend circuits and transferred the new principles onto a second frequency band.

The new prototype was fully tested at the Automotive Galileo Test Environment (GATE) in Aldenhoven, Germany in 2016. Good results were obtained in a number of test drives in real situations exposed potentially to disruption with which the standard GPS equipment commercially available would fail to cope.

Review of the first prototype: the basis of a new receiver

If navigation systems that have high-performance, reliable components are too large, they will not be marketable. In view of the fact that classic group antennas with four individual antennas in a square array have an outside edge of about 30 centimetres, the components for the 4-antenna array in the initial project were considerably reduced in size.

Why group antennas at all?

Combination of several antennas is absolutely necessary if interfering or reflected signals are to be successfully suppressed and the UAV enabled to navigate precisely. Group antennas function in a way reminiscent of the human brain's abillity to judge direction through a noise heard with the ears. They detect interference signals, analyse them to establish the direction of the source, and block them out. This is achieved by means of customised electronics and algorithms which permit beamforming – adaptive shaping and controlling of the signal beams. If there are four channels, up to three sources of interference can be blocked.

What stops the group antennas from being made tinier and tinier?

The distance between the grouped antennas will usually be approximately half the wavelength of the signals to be received. To achieve smaller antennas, the distances between the individual elements have to be reduced. However, if each element is less than half a wave length from the next, the coupling will be intensified. This interaction between the individual detectors decreases the sensitivity of the group to signal direction, defeating the object.

So what was done?

A solution to this basic problem was found in the project stage completed for 2013: from that R&D came a satellite receiver with a group antenna which was reduced to 15x15 cm², had 4 channels, one type of polarisation and a single reception frequency band. Special decoupling and adaptive networks together with receiver circuit and the appropriate algorithmic signal processing served to compensate for the negative coupling effects. IMMS had developed the circuit which amplified the signals (with low noise) and converted them to a frequency range around 75 MHz, in which they could be directly put through an ADC, then subjected to digital processing and evaluation.

Details on the earlier project: www.imms.de

Why more channels?

With the new receiver system being developed from 2014, spot-on navigation must be possible without any failure caused by interference, disturbance and noise. And it would also have to be made even smaller. Again, the receiver has four grouped antennae. But the number of channels has been quadrupled, raising the number of degrees of freedom to 16 from four. This has been achieved by changing from one to two reception bands and from one to two types of polarisation. Redundancy is the welcome result, meaning that absent or disrupted signals can be compensated for.

With the second frequency band on which to receive Galileo E5a-type signals, IMMS has increased the number reception channels from four to eight. Furthermore, the new receiver processes LHCP (left handed circular polarisation) in addition to RHCP (right handed circular polarisation) signals for each of the frequency bands, which is what is meant by dual polarisation. The number of channels is thus effectively doubled, to 16.

Why dual polarisation?

Satellite signals are of their nature an RHCP of the electromagnetic waves. They pass through the atmosphere in a straight line. However, when the satellite is low over the horizon, LHCP signals arrive in addition at the antenna which is horizontal. Likewise, circular polarisation changes for every reflection from right to left or vice versa. For these reasons, the newly designed system processes not only standard RHCP signals, but also those with LHCP. Another potential source of disruption eliminated.

The IMMS contribution

The quadrupling, above all, brought with it much more complex challenges on many fronts: the networks used in decoupling and adaptation, the adapted algorithmic signal processing, and thus, also, for the receiver frontend circuit which IMMS developed as the link between the group antenna and the digital signal analysis electronics. What IMMS developed was an ASIC and a circuit board.

It was necessary to reduce the size of the new receiver to a 10 cm square. The connector for the signals at the antennae was a standard jack, one centimetre wide, for the 16 channels with 16 inputs and outputs distributed over two frontend circuit boards (see Fig. 2). The essential core of each of the two PCBs is the specially developed ASIC.

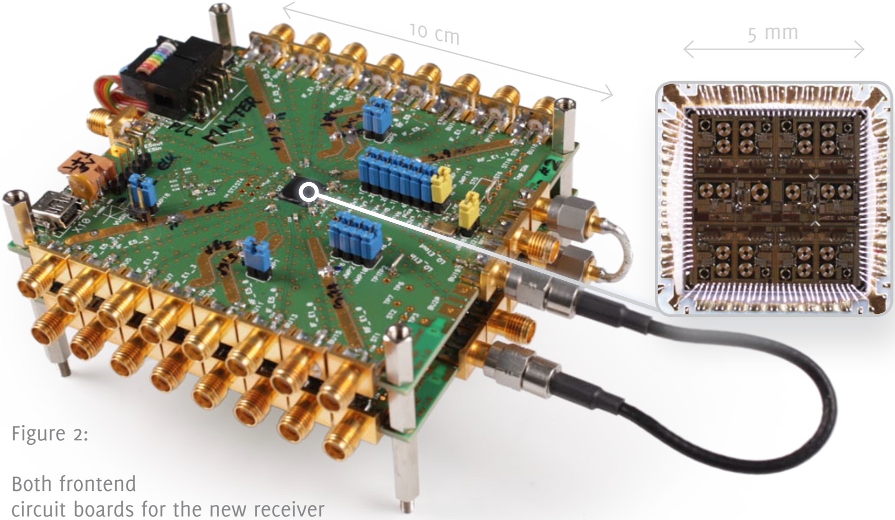

Figure 2:

Both frontend circuit boards for the new receiver together with 2 SMA connectors per channel will fit onto an area 10 cm square situated beneath the group antenna. At the centre of each board there is an ASIC (5 x 5 mm², see detailed graphic) sealed directly onto the board (Chip-on-board technology). Photograph: IMMS.

Development of the frontend ASIC

The receiver has to be capable of suppressing interfering signals which may be more than 100 times stronger than those from a satellite. For this, the entire receiver channel must have strong linearity across a large dynamic range.

The receiver circuit at the frontend handles the weak, high-frequency satellite signals in such a way that they can be subjected to digital processing at the next stage and be sent through the algorithms that will suppress interference. In the frontend circuit, the satellite signals are coherently converted and amplified. The amplification can be set in four levels between 44 dB and 80 dB, which avoids any overdrive in the ensuing ADC (analog-to-digital converter).

More on the IMMS ASIC development possibilities: www.imms.de/ASICs.

Into the new chip, in contrast to the earlier one, IMMS has integrated two frequency bands on one ASIC. The chip has been optimised with insulation of 25 dB for eight reception channels because it is necessary to avoid crosstalk between channels and also because space is so limited on the ASIC. This insulation has been achieved by the spatial disposition of the channels and varied intermediate frequencies. In the complete system, two of these ASICs are employed so that the signals in 16 channels can be processed.

The two identical types of chip on the two circuit boards must interact to ensure that frequency conversion takes place in a coherent fashion using a shared local

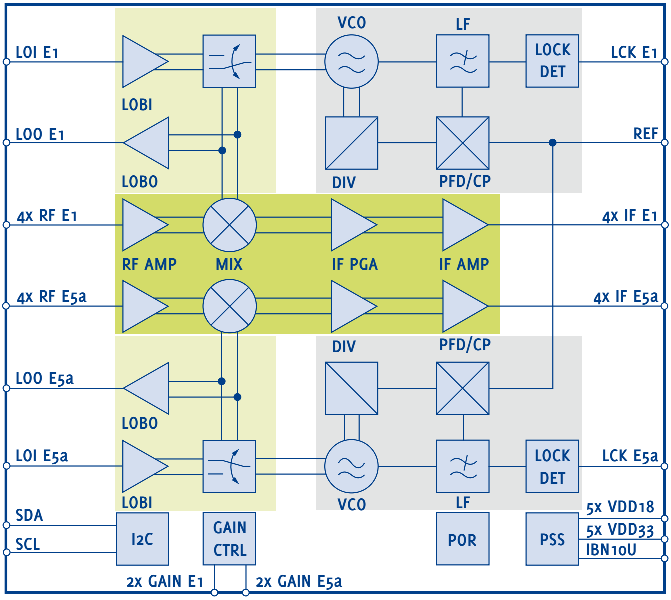

Figure 3:

Schematic diagram of the integrated receiver circuit developed at IMMS.

For greater clarity, a single signal path for E1 and for E5a is shown instead of the four E1 and E5a paths

Signal paths

Local oscillators

Blocks for the master-slave operation

Diagram: IMMS.

oscillator on the eight paths in each frequency band. For each of these bands there is a frequency synthesiser on the chip. The two chips are configured so flexibly from a digital interface (I²C) that at any one time only one chip acts as frequency synthesiser on behalf of both, creating the local oscillators and distributing them to the second chip. It is this master-slave arrangement that makes coherent frequency conversion feasible for all the channels.

More on the IMMS ASIC development possibilities: www.imms.de/ASICs.

The digital I²C interface has many more settings available so that, among other things, energy can be saved by switching off channels not in use, or manufacturing tolerances associated with the technology can be compensated for. In this connection, the amplification of channels that belong together in a frequency band can be calibrated within a tolerance of +/– 1 dB. The configuration desired for the ASIC is automatically loaded from a microprocessor situated on the circuit board when the receiver is switched on.

Development of the frontend board

For the frontend, IMMS has designed, layouted, assembled and evaluated the circuit boards. The ASICs, each with 119 pins, were sealed directly onto the board after first being stuck on and bonded (Chip-on-board technology).

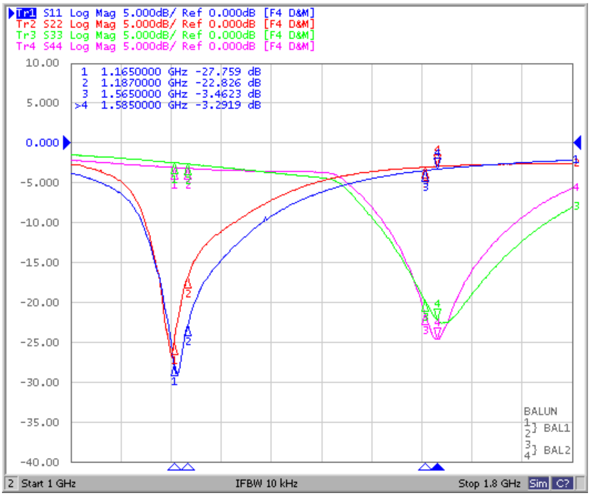

Figure 4:

Adaptation is carried out on the circuit board to enable low-noise signals to pass from antenna to receiver.

This was checked in the IMMS radio frequency measurement lab. The minima in the graphs in each case for two channels of the E1 and E5a satellite frequencies reveal minimal losses during signal transmission.

Diagram: IMMS.

Each of the two boards implements all peripherals that are necessary for operation of either ASIC within the receiver. In addition, the design of the board is such that it has been possible to use it to characterise the ASIC.

Each board provides all necessary supply voltages and a reference oscillator. So that the satellite signals pass from the antenna to the input of the frontend ASIC with little noise, the complex resistances of both have to matched. Wiring and capacitors on the PCBs are used for this. Their performance has been verified by S-parameter measurement using a VNA (vector network analyser) (see Fig. 4). This is the means of achieving the lowest possible signal loss in the two satellite frequency bands (E1 and E5a), as is shown from the minima on the graph. There are also LEDs on the boards to indicate the current status of the analogue frontend.

The board acting as master contains an MCU to load the settings for both ASICs and for the interaction of the two chips described above as the means of achieving coherent frequency modulation. The different amplification levels indicated above can be selected by means of DIP switches for the two frequency bands independently of each other.

More about testing and characterisation: www.imms.de.

Characterisation and testing

Comprehensive measurements carried out at IMMS have shown that all the specifications have been fulfilled or more than fulfilled by the design of the ASIC and board. The large dynamic range and excellent linearity necessary for suppression of interference has been proven by means of S-parameter and large signal measure-

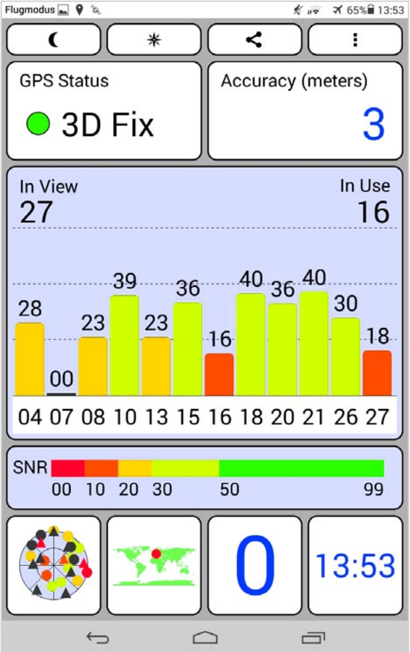

Figure 5. The quality of signal transfer from the frontend to a commercial available Android GPS device with the appropriate app was proved in a shielded measuring lab at IMMS. Signals from 16 satellites were received and decoded. The location was determined at an accuracy of 3m. Image: IMMS.

ment. Overall amplification can be set up to 80 dB and the relation between output signal and input signal is linear up to power of 4 mW or 1.5 Vpp. This being the case, the digitised signals and further processing can be managed optimally.

It has been shown by noise measurements for the individual reception channels that the IMMS frontend has sufficient reception sensitivity. Comparative noise measurements which took place at the noise measurement lab of Ilmenau TU have confirmed the measurements taken at IMMS. To prove that the frequency down-conversion had no adverse effect on accurate copying of the satellite signals and brought in no distortion, the frontend output signals were mixed back into the original frequency situation of the E1 band using a special calibration board. These signals were then broadcast in a shielded measuring chamber at IMMS and recorded with a standard GPS receiver, an Android device containing an app appropriate to analysis of the individual satellite signals. As shown in the example here, the position was determined to an accuracy of within 3 metres which is proof of high signal quality, see Fig. 5.

More detail about infrastructure at www.imms.de.

In measurements during September 2016, the partners in Ilmenau put the entire reception system to the test. Antenna arrays of Ilmenau TU were used. Correct functioning of both polarisation options for the group antenna was tested in respect of GPS signals, see Fig. 1.

Future prospects

The frontend developed by IMMS has met or exceeded the demanding specifications concerning noise and resistance to disruptions. On test drives in real situations at the GATE in Aldenhoven Germany, in October 2016, results were obtained using the complete system that confirmed position accuracy of less than one metre and showed the system was proof against disruption.

To bring the frontend up to meeting industrial conditions, IMMS would have to adapt the method of packaging and bonding of the ASIC. It would also be possible to make the board even smaller and lighter in weight. More compact jacks would help achieve this, or integration into the chip of functions that are present on the PCB. It would, furthermore, be possible to base future development on the present complete system and meet the needs of other applications such as those of driver-less cars, for which the challenges and conditions of use are different.

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DLR Project Management Agency

Publications

S. Irteza, E. Schäfer, R. Stephan, A. Hornbostel, and M. A. Hein, **“Compact Antenna Array Receiver for Robust Satellite Navigation Systems,”** *International Journal of Microwave and Wireless Technologies*, vol. 7, no. 6, pp. 735–745, 2015.
DOI: dx.doi.org/10.1017/S1759078714000907.

Abstract via www.imms.de.

S. Irteza, E. Schäfer, M. Ibraheam, B. Bieske, R. Stephan, and M. A. Hein, **“Beamforming in Compact Antenna Arrays for Robust Satellite Navigation,”** *in IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC), Palm Beach, Aruba, Aug. 2014, Pages 528 – 531,*
SOI: dx.doi.org/10.1109/APWC.2014.6905569

Abstract via www.imms.de.

HoTSens

an ASIC for extremely precise measurement at 300 °C to support industrial efficiency

Device measurements for an ASIC that has put an IMMS method into practice for extremely precise measurements in very hot environments. Photograph: IMMS.

Objectives and overview

In the HoTSens project, integrated sensors and electronics have been developed as a system solution, which will measure pressure and temperature with deviation of less than 2 % either way when the ambient temperature is as high as 300 °C. This is sensor technology which is vital in industrial situations where data must be captured despite extraordinarily high ambient temperatures.

More on the HoTSens project: www.imms.de

No specialised ASICs (application-specific integrated circuits) have so far been available for use at operating temperatures above 225 °C. To enable today's increasingly complex machinery and equipment to be operated safely with the highest possible efficiency in use of resources and energy, the state of each device and process needs to be monitored at many points simultaneously, fast and accurately. The nearer to the process is any sensor and signal-evaluating equipment, the less interference there will be, and the more exactly can the signals be registered and processed. However, bringing such a system closer to the process means that it will need to withstand ever higher temperatures.

The new module has high-temperature electronics integrated into it. The resulting sensor system will amplify and calibrate the primary signals from a combined pressure and temperature sensor in such a way that any potential errors in the pressure signal are ironed out.

IMMS has developed high-temperature ASICs with time-coded signals and adjustment algorithms for precise measurements and has tested and characterised them. For the purpose, a new test setup was first designed and made, then successfully tested. It has an integrated cooling system to enable full semi-automatic wafer testing up to 300 °C. Second, a high-precision substitute bridge circuit has been designed, then constructed and successfully used for the characterisation.

The IMMS solution in detail: Analogue or digital? Better both.

The problem: high impact of heat and tiny measurement signals

The chip is subject to particularly taxing demands if it is in a high-temperature environment. Use of analogue circuits is restricted in such cases, as they may react strongly to heat. The properties of the chip material can alter greatly as the temperature rises, with resulting changes to the properties of the circuit. In turn, the measuring system would become inaccurate or suffer irreversible damage. The signals from the Wheatstone bridge used for measurements in the new combined pressure and temperature sensor are tiny: only between 0 and 10 mV. Heat will have a particularly strong effect because errors like those associated with the offset for the input may well exceed these values.

To compensate completely for this effect involves a huge amount of effort as further compensation is needed for the correction circuits themselves. It is customary to employ an ADC (analog-to-digital converter) to enable the data to be processed digitally. However, under the present requirement of accuracy at +/– 2 % in relation to the maximum value, not even this method will be successful. Yet another difficulty is that the necessary digital circuits would require a very large chip area and complex corrective algorithms.

Remedy: signals time-coded, computation for corrections

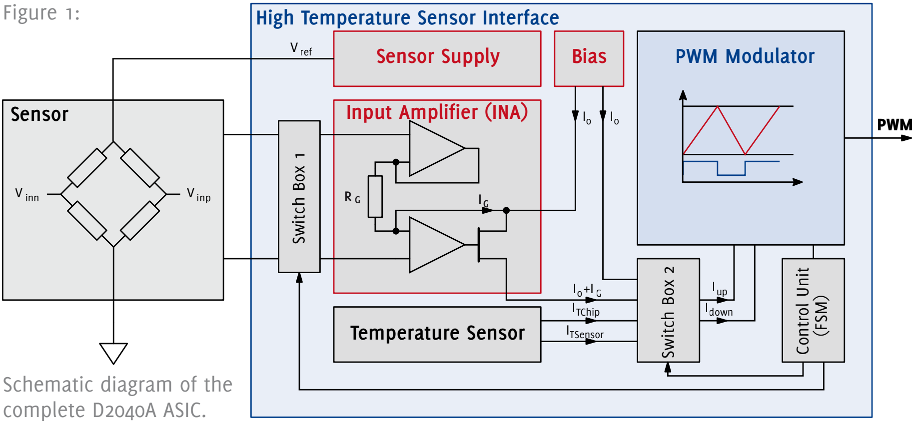
To address the issues, IMMS brought in a new design concept based on time-coded signals (see Fig. 1). The input stage is analogue; the input signal is converted to a current that is switched ON and OFF by a PWM (pulse width modulation) and is thus binary, alterating between only two values, as would be the case with a digital signal.

› Smart Jacket
› ENTOMATIC
› KOSERNA
› HoTSens
› INSPECT
› AFiA

› Contents
* Funding

Article on wafer testing up to 300 °C at www.imms.de.

Figure 1:



Schematic diagram of the complete D2040A ASIC.
Areas exposed to espeacially strong temperature effects are marked in red. Diagram: IMMS.

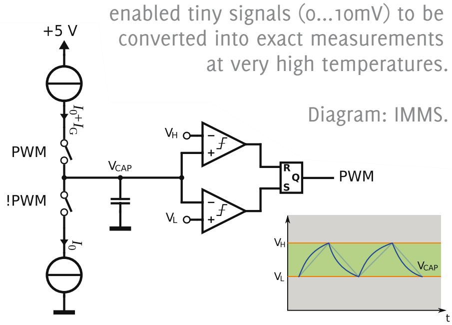
Fig. 2 demonstrates the principle: by charging and discharging a capacity using a current source, it is possible to convert a constant current into timed intervals. The signals at the output are easy to measure using a commercially available MCU (microcontroller unit), for instance. There is no need for an ADC. This is the current state of the art, and yet it is very hard to keep under control when the temperature ranges above 250 °C, which is the aim here: the highlighted areas in Figure1 are still very much influenced by temperature, and the signal alterations due to this may well be as great as the input signal itself: i.e. the offset in the input stage – the error – can lie in a range extending to ±10 mV, which is also the range of the tiny signals from the Wheatstone bridge, again between 0 and 10 mV, on which the measurements depend. In addition, at temperatures above 250 °C the external resistance will alter with temperature change in a non-linear fashion, as does that of the internal reference material. As a consequence, even the supply voltage to the Wheatstone bridge (V_{REF}) varies with the temperature. To compensate for these effects is an inexact science in this temperature range, and a huge computing task at that.

More on the IMMS ASIC development possibilities: www.imms.de/ASICs.

IMMS has taken the PWM procedure described above and extended it so that it is possible to remove from the measured value those elements which reflect temperature and ageing (offset, span, for instance) by simple corrective computation. Two additional measurements are carried out to log current values for the temperature-dependent elements and are taken into account

Figure 2:
Time coding as shown here, using the time-coding principle developed by IMMS, has enabled tiny signals (0…10mV) to be converted into exact measurements at very high temperatures.

Diagram: IMMS.



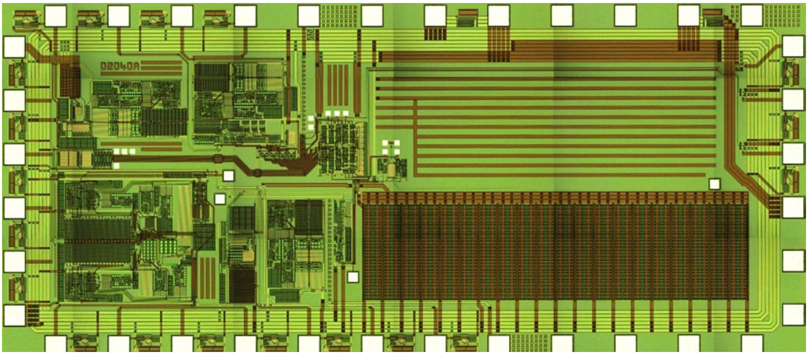


Figure 3: The D2040A chip has been fabricated with the new principle integrated into it. Photograph: IMMS.

before the measured value is shown on screen. This computation achieves the compensation because the PWM is designed with appropriately staggered phases.

Does it really work? Planning the characterisation

High-precision substitute bridge circuit and high-resolution temperature grid

It was necessary to construct a special measuring station to characterise the D2040A. For these purposes, a highly accurate substitute bridge circuit was needed because the input signal is so low at 0...10 mV and is itself produced by a Wheatstone bridge. To enable the chip behaviour at these temperatures to be evaluated, this substitute circuit is heated to 300 °C in a holder sustaining high temperatures. The temperature is decreased very slowly in the cooling process; meanwhile a measurement program is carried out and the data acquired is saved as a time-related heat transfer graph together with the current temperature. By this means it is possible to use a high-resolution temperature grid to establish the offset and amplification values.

More about testing and characterisation: www.imms.de.

These values are then processed as follows. The full-scale deflection is standardised as 1 to provide comparability. Then the offset and amplification are established across the range of temperature and represented in a graphic like that in Figure 3.

An accurate measuring ASIC in heat up to 300 °C

The measurements show impressive accuracy across the whole range of temperature. After correction for linear temperature dependence, the residual error is ± 1.5 % FS (where FS is the full-scale deflection). This residual error accords with an input offset of ± 150 µV – meaning that the input offset (originally up to ± 10 mV) has been reduced a hundredfold or so. The method also disposes of the temperature drift almost entirely. Systems previously available have only been able to operate with

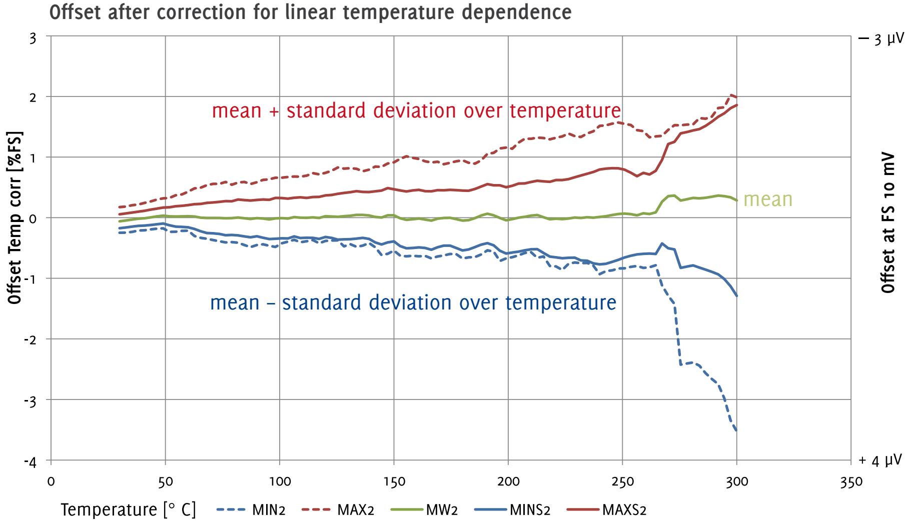


Figure 4: Measurements at accuracy of ± 1.5 % FS (FS being full scale). Diagram: IMMS.

this tiny degree of error if high-quality components were being analysed. Five chips were used in the measurement program.

Resistance to ageing at 300 °C was also evaluated. After 100 hours of constant use in the hot environment, the chip was still coming up to expectations. It will be necessary to carry out a further series of measurements to determine ageing behaviour before the average life of the chip can be established.

Future prospects

The concept newly developed by IMMS to enable very precise readings to be taken from Wheatstone bridges has been built into an ASIC and its efficacy convincingly demonstrated in a high-temperature environment. This prototype provides around 10 – 20 measurements per second and it is thought that it will be possible to raise this rate by a factor of at least 10 on successor chips. The first ASIC created is currently undergoing further examination. A demonstrator is being created which will be available in the course of 2017. It will also be possible to transfer the principles to other technologies where use of an analogue to digital converter is prohibited for cost or other reasons.

More on the HoTSens project: www.imms.de

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

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RESEARCH SUBJECT

INTEGRAED SENSOR SYSTEMS FOR BIOLOGICAL ANALYSIS AND MEDICAL TECHNOLOGY

Experimental setup to measure pH in aqueous solutions with the aid of microelectronics – one of the research stages in achieving a diagnostic platform for automated early diagnosis of cancer. Photograph: IMMS.

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

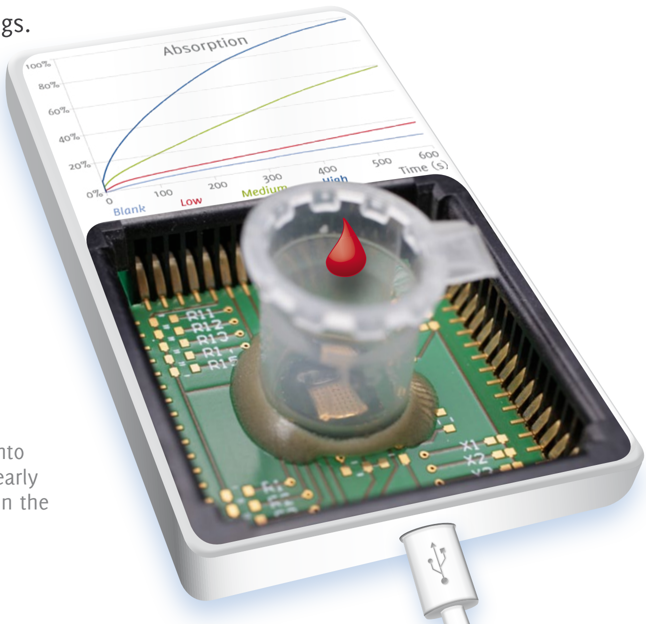
Increasing life expectancy in our societies lead to a rise of serious diseases such as cancer, cardiovascular disorders and dementia and to a growth of related expenditures for diagnostic analysis and therapy. Our research on microelectronic biosensor systems for medical diagnostics and personalised 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.

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.

Projects in this field: www.imms.de.



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.

INSPECT – Microelectronics to recognise cancer early

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

More than 500,000 people a year develop cancer in Germany.[1] Five years after being diagnosed with cancer, depending on the type of tumor, patients' survival rate is between 1 in 5 and 9 in 10.[2] The earlier the disease is discovered, the greater is the chance of cure. It is possible for cancer of the colon, which is the commonest form in Germany, to grow for a decade before giving rise to symptoms.[3] There are certain types of cancer for which the patient's doctor can test rapidly on the spot, obtaining an immediate result and saving costly, time-consuming lab tests.

Present rapid tests no more than qualitative

The present state of the art includes the strip test on which antibody molecules have been deposited. These seeker molecules have a colour marker and will bind the target molecule to them, producing a result within 5 or 10 minutes: the answer is "yes"

1 *https://www.krebshilfe.de/informieren/ueber-krebs/was-ist-krebs/*

2 *im Vergleich zur Allgemeinbevölkerung, http://www.krebsdaten.de/Krebs/DE/Content/Krebsarten/Krebs_gesamt/krebs_gesamt_node.html*

3 *http://www.darmkrebs.de/ueberblick/*

or ”no“ according to the presence of a coloured line. However, varying strength in the colour of this line is not information that the user can interpret. It is also possible for a very pale line to be overlooked.

Future quantitative rapid tests for exact diagnosis

On the other hand, if it were possible to measure the exact concentration of certain molecules in sample fluids, reliable diagnosis could be achieved. Particularly in the case of cancer of the prostate, which is the commonest form of cancer for males in Germany,[4] there would be a great improvement if the on-site diagnostics could include such quantitative analysis. Although the presence of PSA (prostate-specific antigen) may be an indicator of cancer, it is constantly being produced in the male body. A man less than 50 years old will have a PSA concentration of less than 2.5 ng/ml (the unit is in thousand-millionths of a gram, i.e. in nanograms, per millilitre). At over 70, a man will have a level around 6.5 ng/ml. It is possible for these values to vary independently of age; the cause may be inflammation, mechanical irritation or cancer. If there is a carcinoma developing, the patient's PSA concentration will be rising continuously. If the PSA concentration could be measured at regular intervals, reliable early diagnosis and early treatment would result.

Microelectronics to measure antigen concentrations in colon and prostate cancer

In the INSPECT[5] project, IMMS and other partners in Thüringen are developing a biological and microelectronic system of rapid diagnosis for immuno-oncological recognition of colon and prostate cancers in the early stages. It is the role of IMMS to develop the electronics, focussing on signal processing, particularly in the case of very weak signals, and efficient noise suppression for these. The starting point is the knowledge obtained from the GreenSense* project, which worked on a semi-conductor optical sensor array to serve as a diagnostic platform for infectious diseases.

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

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

Preliminary experiments have been carried out to verify the ASIC (application-specific integrated circuit) against the new requirements and the biofunctionalisation of the chip surfaces. The first optical measurements of chemical reactions have also been carried out in direct contact between electronics and chemistry. These constitute the basis of the diagnostic system to be developed by the partners in the period up to 2019.

4 *http://www.krebsdaten.de/Krebs/DE/Content/Krebsarten/Prostatakrebs/prostatakrebs_node.html*

5 *Mikroelektronische Diagnostik-Plattformen für die personalisierte Krebsforschung und Mikro-Bioreaktoren.*

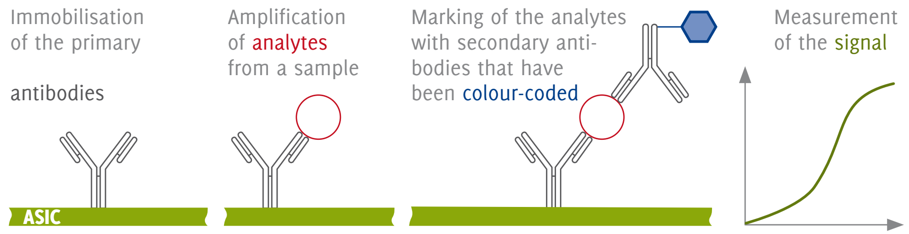


Figure 1: Basic principle, quantitative detection of PSA or haemoglobin analytes. Diagram: Senova/IMMS.

Approach taken and preliminary studies

Fundamental principle and aims of the overall system

The biotechnical principles on which the new test system will be based are comparable with those for the strip test. The interaction between antibody and antigen is intended to enable detection of analytes in a sample: PSA in the case of prostate cancer and haemoglobin in the case of colon cancer.

As shown in Figure 1, the new aspect is that the primary antibodies are fixed vertically on the surface of a microelectronic chip (A). Sample fluid applied to the chip forms invisible antibody-antigen complexes (B) if any of the suspected PSA or haemoglobin antigens are contained in the fluid. It takes a second step to make these visible: secondary antibodies with a coloured marker are added. These dock onto the analytes of the antibody-antigen complexes (C). The coloured solution with the secondary antibodies which are not bound to the surface is then rinsed off. Those which are bound cause a change in the optical density, which is then detected and evaluated by the ASIC (D).

The luminous intensity is measured before and after the reaction, to determine the degree of attenuation. A logarithmic relation is then calculated between the two values. To achieve a diagnosis, the degree of accuracy must lie between 0.01 Bel and 1 Bel.

System setup

These reactions and the measurement process need to take place in a compact, mobile device shielded from light. It should be connected to the device to a computer or laptop using a standard interface. The software should manage the testing, display the data and process the data. The sample is inserted into the reaction chamber situated above the ASIC, so that the sample interacts with the system electrically and mechanically. Light sources produce homogenous illumination at various wavelengths and at a fixed distance from the chip. They will illuminate the sample at constant luminous intensity for the duration of the test. This device is intended to enable doctors to make reliable tests for diagnostic purposes without recourse to the laboratory. The biofunctionalised microelectronics should enable users to test instantly, sparing them the additional effort of sample preparation.

Initial experiments as the foundation for the new chip development

For cancer 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. These low concentrations induce very weak fluctuations in the luminous intensity, between 0.01 Bel and 1 Bel.

IMMS has thoroughly investigated the technical feasibility of achieving this level of accuracy for the purpose of cancer diagnosis. As a first step an already available ASIC was evaluated to see how it would visualise varying levels of brightness in sample fluids where the concentration of particles is known.

This chip is quite large as it was developed for research purposes to meet different requirements: It was intended for detecting infectious diseases and contains a 6 x 7 matrix of photodiodes (Figure 2). It was designed for parallel detection of various pathogens by varied fluctuations in luminous intensity.

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

The optical principle in the signal conversion for this research chip is now to be transferred for use in cancer diagnosis and adapted to the new requirements in a new ASIC design.

TMB (tetramethylbenzidine) substrate solutions were deposited on this chip and the TMBs, were enriched with HRP (the horseradish peroxidase enzyme). The chemical reactions which took place turned the fluids blue. The ASICs were used to measure the gradual attenuation of light due to staining over time. The functionality of the rapid test was simulated using several analyte concentrations to test the electronic system.

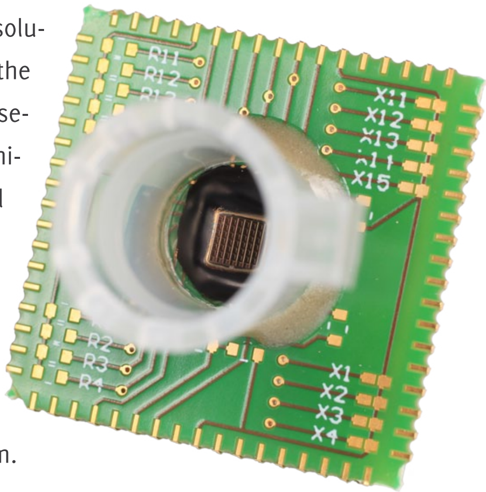
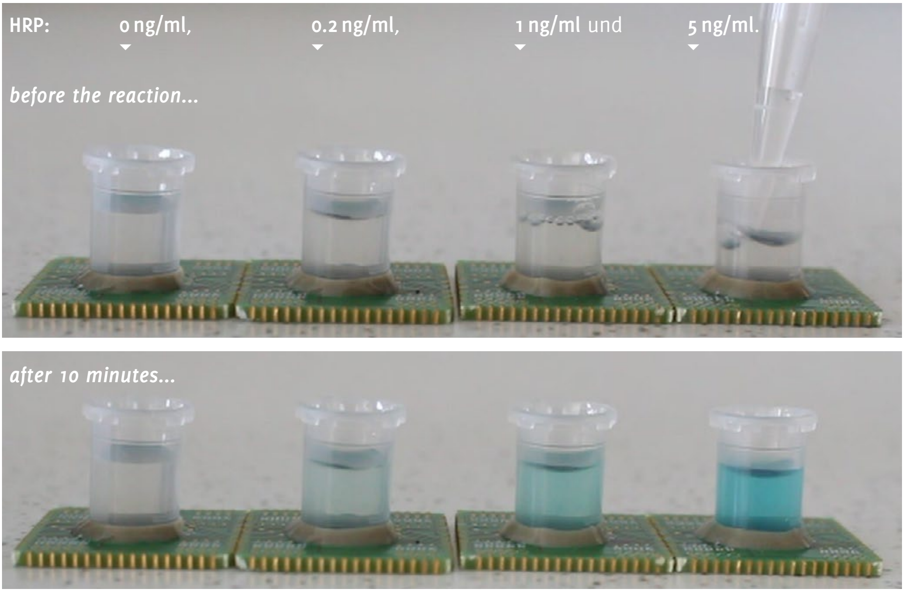


Figure 2: The ASIC (centre) used for the initial work on early cancer diagnosis. Photograph: IMMS.

Figure 3: Staining on conclusion of reaction in the case of four samples containing 0 / 0.2 / 1 and 5 ng/ml of HRP. Photographs: Senova.



Senova, a partner in the project, provided 4 sample solutions which contained 0 ng/ml, 0.2 ng/ml, 1 ng/ml and 5 ng/ml of HRP respectively, as shown in Figure 3.

Various levels of colouration were found. For each sample, on addition of the specified HRP concentration, a brightness value was recorded for each second over a period of 600 seconds. These recordings proved that the alterations in brightness were, indeed in the range 0.01 Bel to 1 Bel and the visualised differences in the reaction processes were consonant with expectations for at least the samples with higher concentration. It is intended to rely this preparatory work in developing correlations for the analyte concentrations which would prove the presence of PSA and haemoglobin.

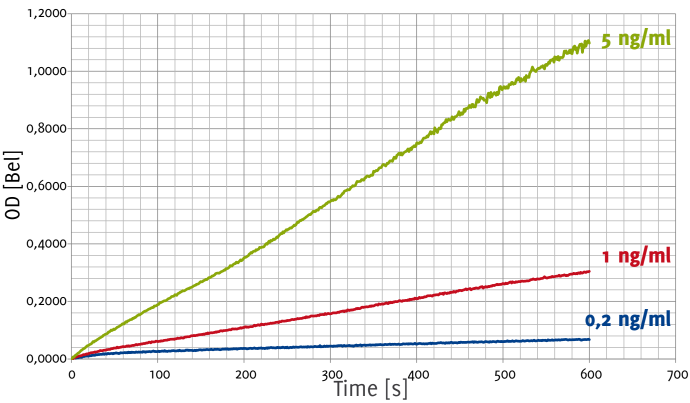


Figure 4:

Luminous intensity variation in the targetted range of 0.01 Bel to 1 Bel.

To simplify the graphic, the sample containing no HRP has been omitted.

Diagram: IMMS/Senova.

Future prospects

The initial work described above on the electronics has confirmed that the technology is in principles suitable for the levels required in the diagnosis of cancer. Tests are being continued through 2017. Attention is now being focussed on the samples with lower concentrations, the use of shorter measuring intervals and tests of robustness by repetition. In addition, Senova is working on further tests using chip surfaces provided with biological functionality and using biological samples on the current chip.

To support Senova in this, IMMS has developed a mobile test system for use in investigating the various parameters associated with early diagnosis of cancer so that Senova can establish exact details for luminous intensity in relation to concentration and improve the accuracy of the graduation as the joint work continues. It should be possible to specify an ASIC on this basis in the course of 2017 which will be smaller, more exact, less affected by noise and better tailored to the application, while at the same time being less costly.

More about testing and characterisation: www.imms.de.

Contact person: Dr. Balázs Németh, balazs.nemeth@imms.de

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

EFRE
EUROPE FOR THURINGIA
EUROPEAN REGIONAL DEVELOPMENT FUND

EUROPEAN UNION

The project in which these results have been achieved has been jointly funded by the federal “Land” of Thüringen with the reference 2015 FE 9159 and by the EU in the EFRE (regional development) context.

The joint partners with IMMS in the project are Senova Gesellschaft für Biowissenschaft und Technik mbH, CDA GmbH, Institut für Bioprozess- und Analysenmesstechnik e.V. and X-FAB Semiconductor Foundries AG.

RESEARCH SUBJECT

HIGH-PRECISION DRIVES

IMMS staff member working on a planar drive system for the PTB (National Metrology Institute of Germany). Photograph: IMMS.

High-precision drives

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.

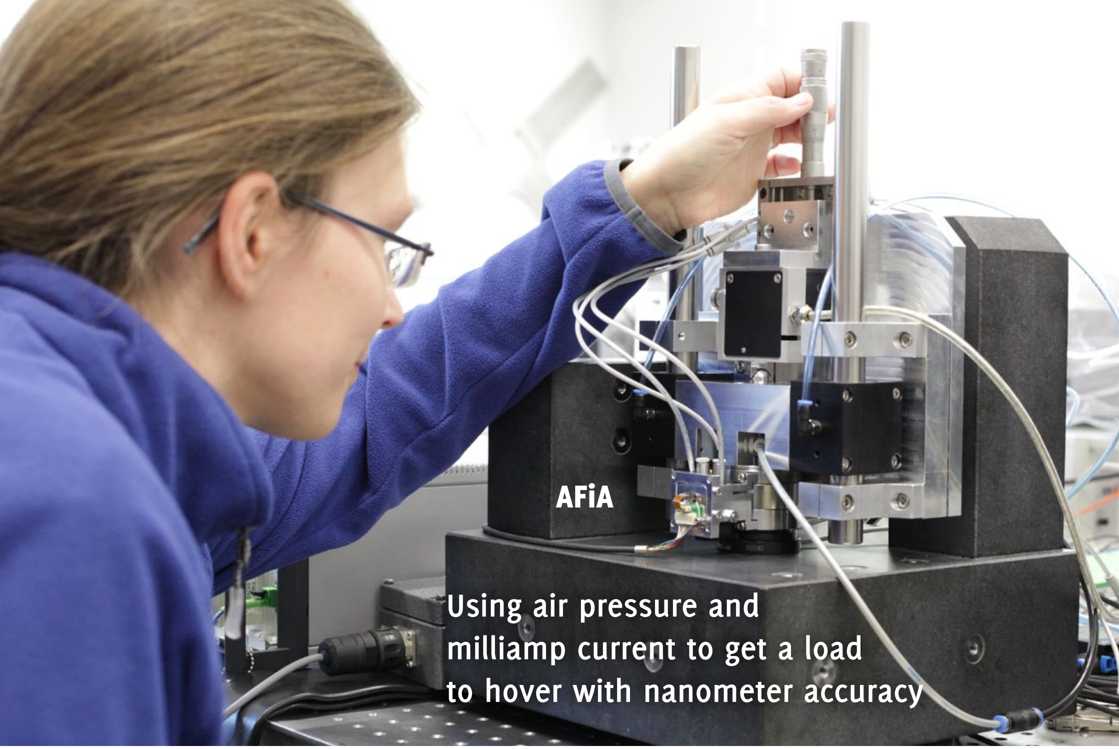
To blaze the trail for the manufacturing of components from the macro-world with the precision that is associated with the micro- and nano-world, we conduct research on the scientific fundamentals and technical solutions to implement nanopositioning systems acting over long distances of travel. Our highly 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.

Planar drive system for the PTB (the National Metrology Institute of Germany)

Mid 2016 saw the start of a project in which IMMS is to develop a planar drive commissioned by the PTB, the National Metrology Institute of Germany. The drive is to be an element of an interferometer metrology instrument at the PTB which will be used to measure exactly the dimensions of objects in a vacuum environment.

For this purpose, the drive will serve to position the objects with high precision in a travel range of 150 mm x 2 mm. It will be the job of IMMS to take the following elements of the drive system through the stages of design and realisation: drive, guide, measuring system and control system. An important focus besides the matter of positioning accuracy and vacuum compatibility will be to minimise thermal influence on the actual measurement area. IMMS will therefore ensure there is a lock-down option for the air-guided slider, to be followed by deactivation of the drive and measuring system.



IMMS has developed a vertical drive to raise and lower objects through 10 mm under active control with nanometre precision. Photograph: IMMS.

Objectives and Overview

To date, manufacturers have always found it extremely difficult to raise loads in the region of 10 kg for industrial purposes and to hold them in a precise position. Nanometer accuracy was always subject to compromise. The very possibility has come through electromagnetic vertical actuators with pneumatic gravity compensators, which can be integrated into many existing precision drive systems.

Systems of this kind are used for purposes which include semi-conductor technology, for instance in order to position reticles. The jigs needed for measuring and structuring such things as substrates, wafers and reticles usually have an (x,y) stage in order to move the object with extreme precision within a plane. These objects are not uniform in height: there is variation in the thickness of wafers and masks or the height of the reticle supports.

Besides, the procedures themselves are carried out in different levels. Here one example is the measuring of stacked images behind an exposure mask and another

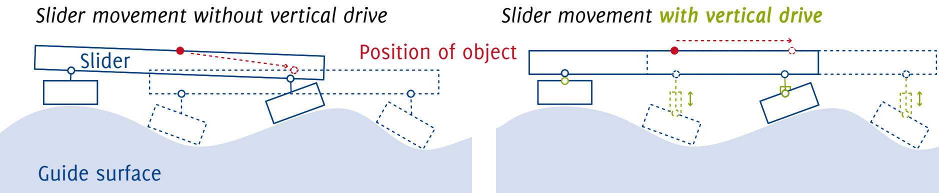


Figure 1: As the flatness of a guide surface, such as this one for an aerostatic guide, is impossible to manufacture with perfect accuracy, there will be variations in height and a slight tilting of the slider as the measured object glides above the surface. The difference in height can be compensated for using vertical actuators. Diagram: IMMS.

example the structuring of wafer layers. Such layers are often only a few nanometres thick; an entire wafer may have a thickness between 0.7 and 0.9 mm.

IMMS has now developed a vertical drive to raise or lower objects with nanometre precision and active control through a range of 10 mm. The raising and lowering is achieved by pneumatic gravity compensation. This controls the amount of force to be applied by the vertical electromagnetic drive by constantly approximating it to zero. As a result there is in effect no current flowing in the actuator coil, which means there is no unwanted source of heat in the measuring space (which would interfere with the necessary precision of measurement by causing expansion of the materials).

A rise in temperature of only 0.01 K, for instance, will cause such a measurement error when a reticle is being measured that the integrated circuits to be produced with it would fail. The new drive will enable objects to be brought into position with no Abbe error, at much greater accuracy than previously for sampling or processing.

Details

Basic principle

These precision drives rely on obtaining position data from three laser interferometers placed around the slider (see Fig. 2). When the reflecting corner of the slider moves, laser beams are reflected from the plane mirror surfaces, so that distance can be measured. Following the Abbe comparator principle, the length to be measured on the test piece and the scale on the measurement instrument should be flush so as to avoid the errors known as first-order tilt error. This means that the best point for sampling or processing a test piece which requires the most precise of measurement is the Abbe point (see Fig. 2). In practice, the implication is that the

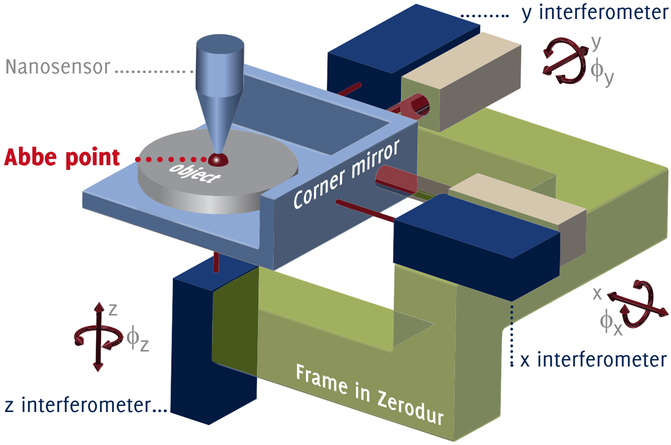


Figure 2:

Measuring or processing an object at the "Abbe point".

Diagram: TU Ilmenau, edited by: IMMS.

object should be inside a corner mirror and that the imaginary extensions of all laser beams along the x, y and z axes of the interferometer should meet at the sampling (or processing) point, as required in the spatial Abbe comparator principle. Applying this basic measurement principle, the corner mirror and test pieces should be raised or lowered as their thickness or surface profile requires, so that the sampling point on the surface of the measured object is always brought to the Abbe point.

State of the art and current challenges

In numerous applications, on the vertical (z) axis the typical range of movement to be set and measured will lie between 1 and 10 mm. Methods of raising or positioning the object and the corner mirror will have to be found which will work to nanometer precision, i.e., if possible, managing without any observable thermal loss. Expansion of the materials cannot otherwise be avoided.

The present state of the art is either to combine spindle drives with piezoelectric drives or to combine intricate spring mechanisms with voice coil actuators. As the basis of all these systems is mechanical contact, they are not proof against friction or wear. No methods known to date have been capable of achieving a vertical movement on the nanometer scale, or at least only capable with considerable compromise in respect of fine adjustment and life expectancy. It is a major challenge to keep the load-bearing capability absolutely constant during movement along the z axis for several millimeters and to achieve effectively friction-free guidance for this vertical motion.

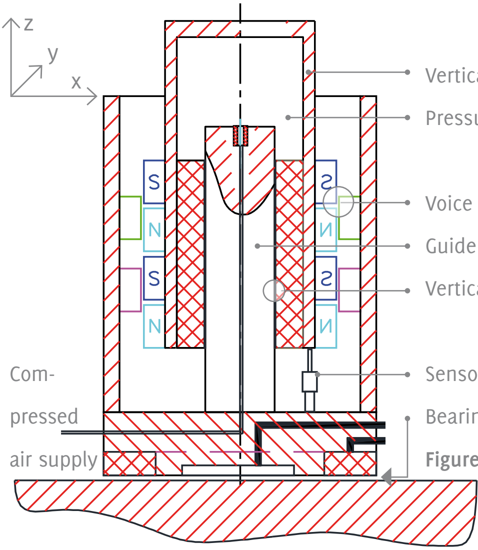


Figure 3: Schematic representation of an air bearing guidance system with vertical actuator and weight compensation. Diagram: IMMS.

Execution, development

This is where IMMS comes in. The design shown in Figure 3 combines a voice coil drive with air-bearing, i. e. an electro-magnetic vertical drive for raising the object on the z axis, with a pressure chamber that compensates for gravity. The chamber is filled from a pressure reservoir; the highly accurate pressure control constantly matches the pressure to the load being borne. This principle enables the power required from the voice coil drive to be continuously brought down to approximately zero, so that virtually no heat is generated. The settings for the pressure control are regulated at all times by the current flowing in the electro-magnetic actuator. If the parameters for the settings are suitably planned and structured, even loads of several kilograms can be raised and lowered with heat losses of only a very few milliWatts from the actuator (cf. Fig. 5). The design includes a cooling circuit in the immediate vicinity of the actuated coil to conduct this tiny amount of residual heat away.

More on actuator systems at: www.imms.de.

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

The system is expected to find application in respect of a load that remains constant over time. The only changes to the load will, on the whole, derive from possible "bounce" in the guide elements due to the movements of the guided stage in the in the x and y axes.

The friction-free functioning achieved is thanks to a special seal in the form of a radial gap only a few micrometers wide between the pressure chamber and the cylindrical bearing.

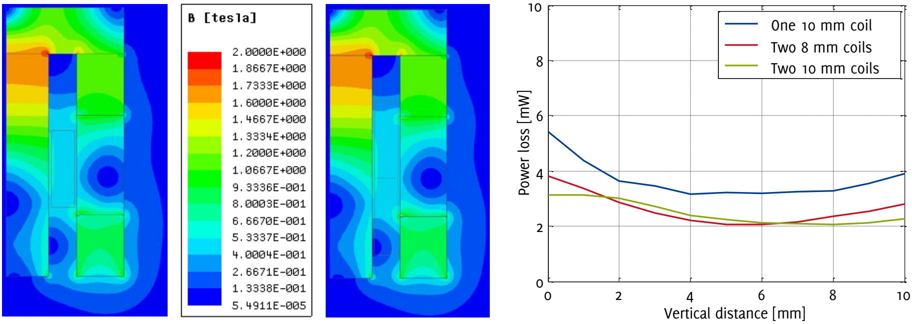


Figure 4: FE analysis of one version of the electromagnetic actuator with single-phase (l.) and two-phase (centre) coils; also shown is the heat loss calculated for a set distance of 10 mm carrying a load of 50 g (r.). Diagrams: IMMS.

With the aim of maximising compactness and an efficiency and ease of cooling the actuator system, IMMS has designed different versions of the vertical actuator, so far with roughly calculated dimensions, and has evaluated the different types. Finite element calculation (FEM) has been applied to a selection of these configurations to assist in the precise dimensioning, design and fabrication of all parts – the structural mechanics, the magnetic features and the thermal phenomena. There are also sealing and extraction channels for the air guiding components included on the finished prototype which will enable the system to be used in a vacuum.

More on our FEM services at www.imms.de.

After fabrication, the vertical actuators were installed into a measuring stage developed specifically for the purpose by IMMS which relies on a high-resolution laser interferometric measuring system. They were then subjected to measurement for reference purposes and tested experimentally. Heat loss graphs were recorded with this combined instrument for a range of loads and positioning movements; also, the reactions to the control system were investigated. Figure 5 shows the actuator in cross-section and a schematic view of the measuring apparatus.

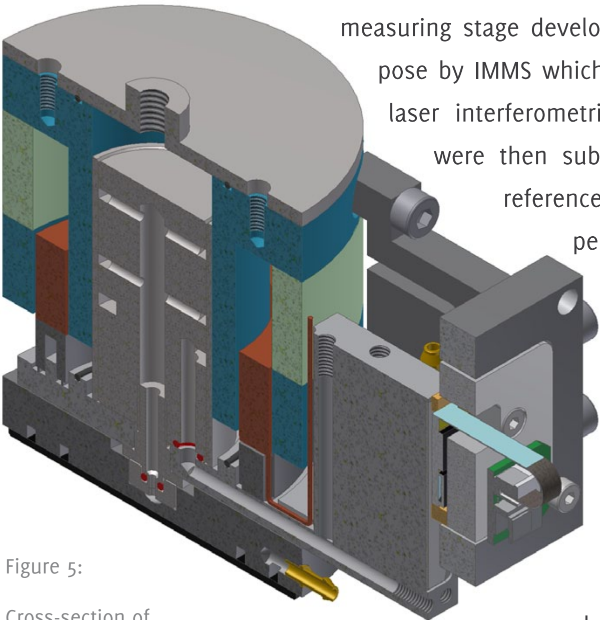


Figure 5:

Cross-section of the vertical actuator. Diagram: IMMS.

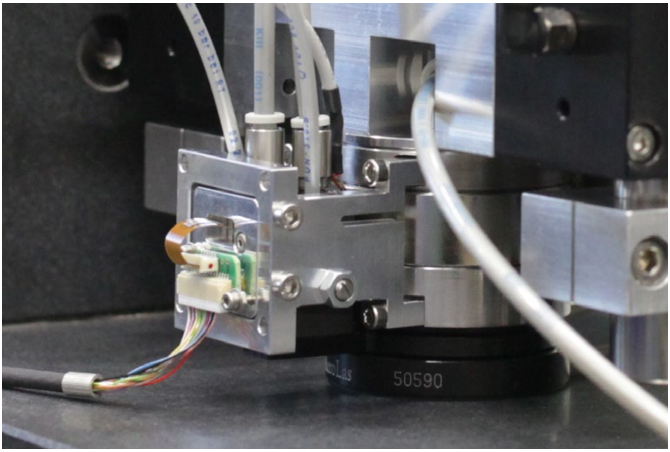


Figure 6:

Actuator prototype installed in testing station.

Photograph: IMMS.

Future prospects

The development of this electrodynamic vertical actuator means that researchers or manufacturers can now raise a measuring platform on which there is a relatively heavy load, almost entirely without the mechanical inefficiency which would cause heat to be generated. The drives previously on the market, even those working in a vacuum, can now be fitted with this new system and will thus be vastly improved. All that will be necessary is to install three of the new actuators on one platform of a positioning system. The effect will be not only exact manipulation of the height of the load but also extremely sensitive control of the tilt of the platform.

The vertical actuator was developed at IMMS as a close collaboration between IMMS, the AeroLas company and the Production and Precision Metrology department of Ilmenau University of Technology.

Contact person:

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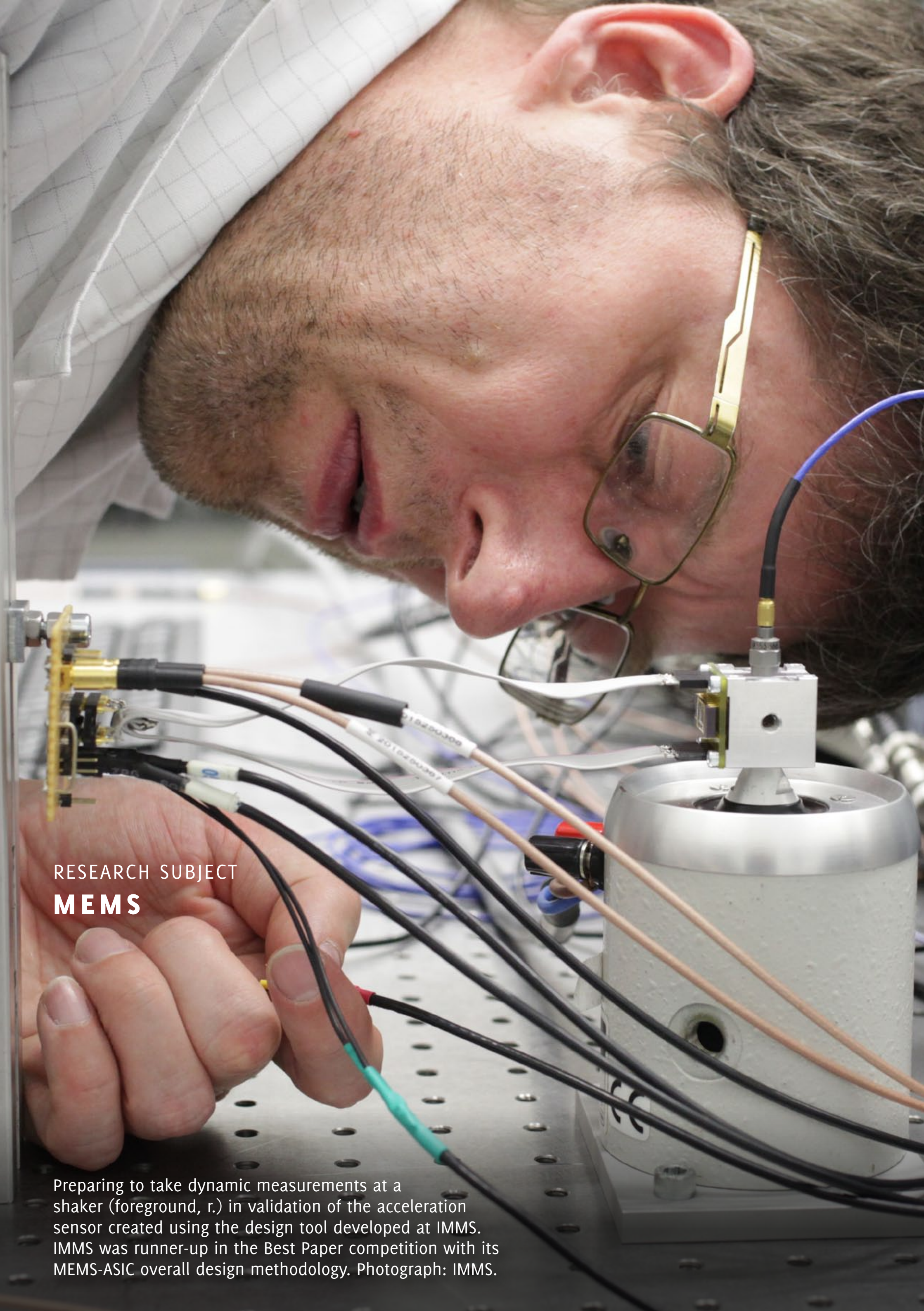
Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

ZIM Zentrales Innovationsprogramm Mittelstand

The AFiA project has been funded by the German Federal Ministry for Economic Affairs and Energy (BMWi) in accordance with parliamentary decree under the reference KF2534513PO4.



RESEARCH SUBJECT

MEMS

Preparing to take dynamic measurements at a shaker (foreground, r.) in validation of the acceleration sensor created using the design tool developed at IMMS. IMMS was runner-up in the Best Paper competition with its MEMS-ASIC overall design methodology. Photograph: IMMS.

Highlights of 2016 in our MEMS research

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

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

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

Best Paper Award Runner-Up: MEMS-ASIC fully combined design system

At the 13th International Conference on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design in Seville, Spain, with the short name SMACD 2016, IMMS achieved runner-up status in the Best Paper Award for Systematic MEMS ASIC Design Flow using the Example of an Acceleration Sensor. The paper contained results from the MEMS2015* project which was completed in 2015. In the project, IMMS applied an approach that would combine and harmonise into a single whole the design of the mechanical and the electronic components of MEMS. Thanks to the novel composite design methodology which was developed, a MEMS can now be simulated and verified as a single unified system, so that errors can be recognised and remedied early.

More on the MEMS2015 project at www.imms.de.

An essential aspect is a design tool applying computer-aided design to electromechanical sensors. This is software which was first created for unidimensional acceleration sensors in XM-SC, the SOI technology of X-FAB AG. The tool works uses an algorithm developed by IMMS to compute the various mechanical design possibilities likely to match the customer's requirements. Further, it is a source of sensor models which can be integrated into established design tools, generating the necessary mask layouts for the manufacturing stage.

Working on a MEMS 3D vibrometer measuring station for the new generation of MEMS.*
Photograph: IMMS.

IMMS has validated the innovative tool and practice by designing an accelerometer (acceleration sensor with high-precision signal evaluation) and then characterising it after fabrication. In the context of the RoMulus* project which began in 2015, the design tool (originally for a unidimensional sensor) is being extended to 2- and 3-dimensional sensors.

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

A MEMS 3D vibrometer measuring station for the new generation of MEMS

Thanks to the EFRE funding which has been agreed, IMMS has been able to add to its research infrastructure the means of testing MEMS with a vibrometer. The new 3D system enables both out-of-plane and in-plane vibrations to be measured, which means that new classes of sensors such as multi-axial inertia sensors can now be characterised in-house.

MEMS-3D-Vibro at www.imms.de.

Another addition is the new broadband amplifier, in the band between 9 and 250 MHz with power of 200 W. Among other things, this enables the latest types of pressure sensor with their smaller, thicker membranes and greater stiffness than earlier versions of pressure sensor to be triggered electrostatically.

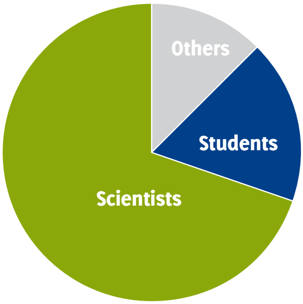
The project has been jointly funded by the federal “Land” of Thüringen with the reference 2015 FGI 0010 and by the EU in the EFRE (regional development) context as a means of improving the instrumental infrastructure to research.

PROOF THROUGH FACTS AND FIGURES

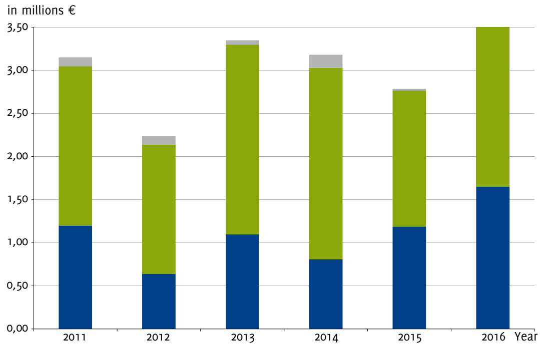
Preparing to take measurements at the wafer level in the class 7, DIN EN ISO 14644-1 clean-room measuring lab at the Erfurt section of the Institute. In the image: 300 mm wafer prober/SensorLab.* Photograph: IMMS.

Facts and Figures 2016

Staff



Project income:
Revenues from industry / Public funding / Miscellaneous



2016 saw 75 members of staff working at IMMS. There were 51 employed as scientists and 13 (FTE[1]) students, i. e. 85 % of the entire staff, who were directly involved in research and development.

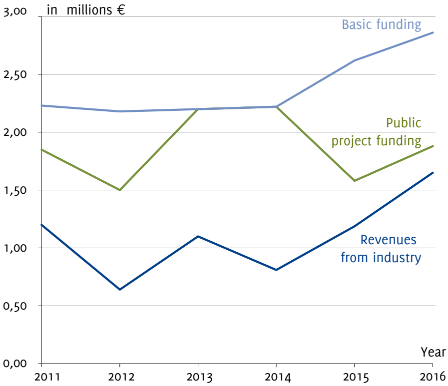
The 13 full-time equivalent posts were actually filled by 40 students in all who were taking the opportunity offered by IMMS to deepen and supplement their studies by practical research. There were 22 students on formal internships and 18 working as paid assistants. IMMS was supporting and supervising 5 dissertations for the BSc and 4 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.

Revenues from industrial research commissions in 2016 were about 13 % more than that of the previous year and revenues from public funding 36 % more. The earnings proportion is 61 %. This proportion is reflected in the income trend. Overhang of payments at year-end means that the increase in public-funded project income is down by 19 %. What is significant, however, is that income from industrial commissions showed an increase of 39 % in 2016. For the next three years (2017 – 2019), IMMS is expecting growth in both areas. This is due in great part to the Institute's strategy

More on funding at www.imms.de.

1 **FTE** *Full-time equivalent*



of tackling consistently the demand for its skills and products found in industry and society as a whole.

The great majority of IMMS projects is carried out jointly with industrial partners. This 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. This is to the benefit of SMEs most of all. The conversion process can be stabilised if the SMEs are combined into regional, product-oriented value-added supply chains. Access to innovation-driven markets is coming more and more to require systems competence in the design and manufacture of products, using micro- and nano-technologies. IMMS is excellently placed in this respect.

Thüringen as federal “Land” maintained its level of support in 2016 for IMMS to keep its place in the context of science for industry. The work IMMS could do in conjunction with regional SMEs benefited above all from this.

More on funding at www.imms.de.

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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

Lange Nacht der Technik (The Long Night of Technology) May 2016, IMMS Ilmenau *(demonstrations, lectures)*

VDMA LabTour Industry 4.0 August 2016, IMMS Ilmenau *(lecture, guided tour)*

20 Years of IMMS September 2016, TU/IMMS Ilmenau *(colloquium, formal ceremony, lectures, live demos, expo, guided tours)*

1st edaBarCamp November 2016, Hannover *(IMMS acted as initiator and co-organiser)*

Current events at www.imms.de.

Trade fairs

Hannover Messe April 2016: IMMS as exhibitor (MICA booth) and winner of the MICA competition; June 2016: MICA network launch *(demonstrations, lectures)*

MEDICA November 2016, Düsseldorf *(live demo, co-exhibitor on the Diagnostik-Net-BB booth)*

Publications

Conferences with contributions by IMMS – an overview

EAS 2016 8th GMM Workshop ”Energy-autonomous Sensors“, February 2016, Renningen, Germany *(lecture)*

TuZ 2016 28th GI/GMM/ITG Workshop on testing methods and reliability for circuits and systems, March 2016, Siegen, Germany *(2 poster presentations)*

DATE 2016 ”Design, Automation and Test“, March 2016, Dresden, Germany *(2 lectures, exhibition)*

2. Thüringer Maschinenbautag (2nd Mechanical Engineering Day in Thüringen) June 2016, Erfurt, Germany *(poster presentation)*

SPITSE 2016 3rd International Scientific Symposium ”Sense. Enable. SPITSE. 2016“, Moskau/Smolensk, Russia, June 2016, *(2 poster presentations)*

elmug4future 2016 June 2016, Friedrichroda, Germany *(lecture)*

SMACD 2016 13th International Conference on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design, June 2016, Lisbon, Portugal *(lecture, Best Paper Award Runner-Up)*

FDL 2016 Forum on specification & Design Languages, September 2016, Bremen, Germany *(lecture and Best Paper Award)*

M2M Summit 2016 Oktober 2016, Düsseldorf, Germany *(lecture)*

12. Schmalkalder Werkzeugtagung November 2016, Schmalkalden *(lecture)*

Workshop on High-Temperature Electronics November 2016, Duisburg *(lecture)*

Workshop – Economy 4.0 at TITK e.V. December 2016, Rudolstadt *(lecture)*

Reviewed Publications

Systematic MEMS ASIC Design Flow using the Example of an Acceleration Sensor, Jenny Klaus[1]. Roman Paris[1]. Ralf Sommer[1]. *13th International Conference on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design (SMACD) 2016, 27–30 June 2016, Lisbon, Portugal,* pp. 1–4, **DOI: http://doi.org/10.1109/SMACD.2016.7520730,** (Best-Paper-Award-Runner-Up).

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Tri-Gate Al0.2Ga0.8N/AlN/GaN HEMTs on SiC/Si-substrates, Wael Jatal[1]. Uwe Baumann[2]. Heiko O. Jacobs[1]. Frank Schwierz[3]. Jörg Pezoldt[1]. *Materials Science Forum,* ISSN: 1662-9752, Vol. 858, pp. 1174–1177, **DOI: https://dx.doi.org/10.4028/www.scientific.net/MSF.858.1174,** ©2016 Trans Tech Publications, Switzerland. [1]FG Nanotechnologie, Institut für Mikro- und Nanotechnologien MacroNano® and 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® and Institut für Mikro- und Nanoelektronik, TU Ilmenau, Postfach 100565, 98684 Ilmenau, Germany.

Investigations of metal systems in a silicon ceramic composite substrate for electrical and thermal contacts as well as associated mounting aspects, M. Fischer[1]. T. Welker[1]. B. Leistritz[2]. S. Gropp[1]. C. Schäffel[2]. M. Hoffmann[1]. J. Müller[1]. *Ceramic Interconnect and Ceramic Microsystems Technologies, Additional Conferences (Device Packaging, HiTEC, HiTEN, & CICMT): May 2016*, Vol. 2016, No. CICMT, pp. 000107-000110, **DOI: http://dx.doi.org/10.4071/2016CICMT-WA22.** [1]Institut für Mikro- und Nanotechnologien MacroNano®, TU Ilmenau, Postfach 100565, 98684 Ilmenau, Germany. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Embedded tutorial: Analog-/mixed-signal verification methods for AMS coverage analysis, Erich Barke[1]. Georg Gläser[2]. Hyun-Sek Lukas Lee[1]. Markus Olbrich[1]. Andreas Fürtig[3]. Lars Hedrich[3]. Carna Radojicic[4]. Christoph Grimm[4]. Fabian Speicher[8]. Stefan Heinen[8]. Gregor Nitsche[6]. Eckhard Hennig[5]. Wolfgang Nebel[7]. *2016 Design, Automation & Test in Europe Conference & Exhibition (DATE), Dresden, 2016*, pp. 1102–1111, **http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7459473&isnumber=7459269.** [1]Institute of Microelectronic Systems, Leibniz Universität Hannover, Germany. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [3]Johann Wolfgang Goethe-Universität, Germany. [4]University of Kaiserslautern, Germany. [5]Reutlingen University, Germany. [6]OFFIS - Institut für Informatik Oldenburg, Germany. [7]University of Oldenburg and OFFIS, Germany. [8]RWTH Aachen, Germany.

6D planar magnetic levitation system - PIMag 6D, Christoph Schäffel[1]. Michael Katzschmann[1]. Hans-Ulrich Mohr[1]. Rainer Glöss[2]. Christian Rudolf[2]. Carolin Walenda[2]. JSME Mechanical Engineering Journal, Vol. 3 (2016) No. 1 p. 15–00111, The Japan Society of Mechanical Engineers, **DOI: http://doi.org/10.1299/mej.15-00111**. [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [2]Physik Instrumente (PI) GmbH & Co. KG, Karlsruhe, Germany.

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Publications in journals

ANCONA – Analog/Mixed-Signal Verifikationsmethoden für die AMS Coverage-Analyse, Andreas Fürtig[3]. Georg Gläser[2]. Christoph Grimm[4]. Lars Hedrich[3]. Stefan Heinen[6]. Hyun-Sek Lukas Lee[1]. Gregor Nitsche[5]. Markus Olbrich[1]. Ralf Popp[7]. Thiyagarajann Purusothaman[4]. Carna Radojicic[4]. Ralf Sommer[2]. Fabian Speicher[6]. Dieter Treytnar[7]. Newsletter edacentrum 01/02 2016, Seite 05–20. [1]Institute of Microelectronic Systems, Leibniz Universität Hannover, Germany. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [3]Johann Wolfgang Goethe-Universität, Germany. [4]University of Kaiserslautern, Germany. [5]OFFIS - Institut für Informatik Oldenburg, Germany. [6]RWTH Aachen, Germany. [7]edacentrum, Germany.

Presentations and Posters

Gateway als Bindeglied zwischen Sensor und Business, Tino Hutschenreuther[1]. *Workshop Wirtschaft 4.0 am TITK e.V. – Digitale Sensorik und Vernetzung sowie smarte Datenanalysen und zukünftige Geschäftsmodelle, 6. Dezember 2016, Rudolstadt.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Design and characterization of a high-temperature pressure measurement system, Georg Gläser[1]. *Workshop on High Temperature Electronics, 29. – 30. November 2016, Duisburg.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Projektvorstellung „Mittelstand 4.0“, Frank Spiller[1]. *12. Schmalkalder Werkzeugtagung, 3. – 4. November 2016, Schmalkalden.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Knowing your A/MS system's Limit: System Acceptance Region Exploration by using Automated Model Refinement and Accellerated Simulation, Georg Gläser[1]. Hyun-Sek Lukas Lee[2]. Markus Olbrich[2]. Erich Barke[2]. *Forum on specification & Design Languages, FDL 2016, 14. – 16. September 2016, Bremen, Germany.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. 2Institute of Microelectronic Systems, Leibniz Universität Hannover, Germany.

Vorstellung IMMS und Arbeiten zu Industrie 4.0, Tino Hutschenreuther[1]. *VDMA LabTour Industrie 4.0, 23. August 2016, Ilmenau.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

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An Approach to Extract Significant Features for Vehicle Classification Based on Magnetic Field Sensor Data, Vladimir SHKODA[1]. Sylvia BRAEUNIG[1]. Marco GOETZE[2]. Hannes TOEPFER[1,2]. *Sense. Enable. SPITSE, 2016, 20. – 24. Juni 2016, Moskau, Russland.* [1]Ilmenau University of Technology, Institute for Information Technology, Germany. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

On the Role of Wireless Sensor Networks for Intelligent Transportation Systems, Silvia KRUG[1]. Jochen SEITZ[1]. Elena CHERVAKOVA[2]. Hannes TOEPFER[2]. *Sense. Enable. SPITSE, 2016, 20. – 24. Juni 2016, Moskau, Russland.* [1]Communication Networks Group, Technische Universität Ilmenau, Ilmenau, Germany. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Flexible Hardware/Softwareplattformen für intelligente Industrie-4.0-Geräte, Tino HUTSCHENREUTHER[1]. Wolfram KATTANEK[1]. *elmug4future, Technologiekonferenz 2016, 21. Juni 2016, Friedrichroda.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Intelligente Lösungen für Industrie 4.0 – Diagnose und Überwachung in industriellen Anlagen, Tino HUTSCHNREUTHER[1]. *2. Maschinenbautag, 15. Juni 2016, Erfurt.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Adaptive Wireless Ad-hoc Sensor Networks for Long-term and Event-oriented Environmental Monitoring, Jan BUMBERGER[1]. Hannes MOLLENHAUER[1]. Paul REMMLER[1]. Andrei Marian CHIRILA[1]. Olaf MOLLENHAUER[2]. Tino HUTSCHENREUTHER[3]. Hannes TOEPFER[4]. Peter DIETRICH[1,5]. *European Geosciences Union General Assembly, EGU 2016, 17. – 22. April 2016, Open Session on Geosciences Instrumentation and Methods, Vienna, Austria.* [1]UFZ - Helmholtz Centre for Environmental Research, Monitoring and Exploration Technologies - MET, Leipzig, Germany. [2]TETRA Gesellschaft für Sensorik, Robotik und Automation mbH, Ilmenau, Germany. [3]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [4]Technische Universität Ilmenau, Department of Advanced Electromagnetics, Germany. [5]Eberhard Karls University, Centre of Applied Geosciences, Tübingen, Germany.

Identification of Critical Scenarios in AMS Verification: Methodology for Finding the Safe Operating Area of AMS Systems, Georg GLÄSER[1]. Hyun-Sek Lukas LEE[2]. Markus OLBRICH[2]. Erich BARKE[2]. Eckhard HENNIG[3]. *Design Automation and Test in Europe (DATE) 2016, 14. – 18. März 2016, University Booth, Embedded Tutorial: Analog-/*

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Mixed-Signal Verification Methods for AMS Coverage, Dresden, Germany. [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [2]Institute of Microelectronic Systems, Leibniz Universität Hannover, Germany. 3Reutlingen University, Germany.

Hörbarmachung von Ultraschallsignalen, Peter Holstein[1]. Nicki Bader[1]. A. Tharandt[1]. R. John[1]. S. Uziel[2]. D. Januszko[2,3]. T. Hutschenreuther[2]. *Fortschritte der Akustik – DAGA 2016, 42. Jahrestagung für Akustik, 14. – 17. März 2016, Aachen, Germany.* [1]SONOTEC Ultraschallsensorik Halle GmbH, Nauendorfer Str. 2, 06112-Halle (Saale), Germany. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [3]Fakultät für Elektro- und Informationstechnik, Technische Universität Ilmenau, Germany.

Nanopositioning and nanomeasuring technology – following the challenges of nanofabrication, E. Manske[1]. T. Hausotte[1]. R. Füßl[1]. T. Fröhlich[1]. M. Hofmann[1]. I. Rangelow[1]. J. Reger[1]. C. Schäffel[2]. S. Sinzinger[1]. R. Theska[1]. *11th Seminar on Quantitative Microscopy (QM) and 7th Seminar on Nanoscale Calibration Standards and Methods, Dimensional and related measurements in the micro- and nanometre range, March 9 – 11, 2016, Wroclaw, Poland.* [1]Competence Centre „Nanopositioning and Nanomeasuring Machines, Department of Mechanical Engineering, Technische Universität Ilmenau, 98684 Ilmenau, Germany. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Testschaltung für MEMS-Inertialsensoren-Auswerte-ASIC, Roman Paris[1]. Peter Kornetzky[1]. Jenny Klaus[1]. *Testmethoden und Zuverlässigkeit von Schaltungen und Systemen – TuZ 2016, 6. – 8. März 2016, Siegen, Germany.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Hochtemperatur-Wafertest bis 300°C, Marco Reinhard[1]. Ingo Gryl[1]. Ulrich Liebold[1]. André Richter[1]. *Testmethoden und Zuverlässigkeit von Schaltungen und Systemen – TuZ 2016, 6. – 8. März 2016, Siegen, Germany.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany.

Adaptiver Frontend-ASIC für elektrostatische Energy-Harvester, Benjamin Saft[1]. Eric Schäfer[1]. Andre Jäger[1]. Alexander Rolapp[1]. Eckhard Hennig[2]. *8. GMM Workshop Energieautarke Sensorik 2016, 25. – 26. Februar 2016, Renningen, Germany.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, D-98693 Ilmenau, Germany. [2]Reutlingen University, Germany.

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Freistaat Thüringen
Hier hat Zukunft Tradition.

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DFG Deutsche Forschungsgemeinschaft

Abbreviations

ADC	*Analog-to-digital converter*
ASIC	*Application-specific integrated circuit*
CMOS	*Complementary metal–oxide–semiconductor*
CPS	*Cyber-physical system*
DAC	*Digital-to-analog converter*
EDA	*Electronic Design Automation*
FEM	*Finite element method*
FPGA	*Field Programmable Gate Array*
FTE	*Full-time equivalent*
HTTPS	*HyperText Transfer Protocol Secure*
IC	*Integrated Circuit*
ICT	*Information and communications technology*
IP	*Intellectual property*
SME	*Small and medium-sized enterprises*
LTE	*Long Term Evolution, 4th generation mobile communication standard*
MEMS	*Micro-electro-mechanical system*
PWM	*Pulse width modulation*
RF	*Radio frequency*
RFID	*Radio-frequency identification*
SiCer	*Silizium-Keramik-Verbundsubstrattechnologie*
SoC	*System-On-Chip*
TU	*Technische Universität (University of Technology)*

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