IMMS

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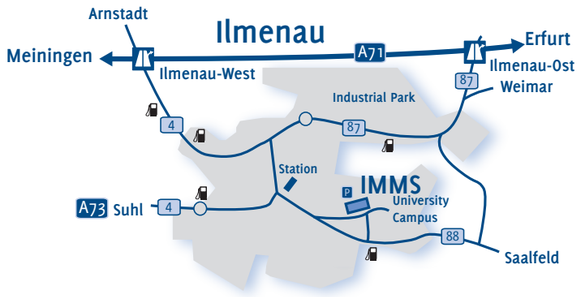

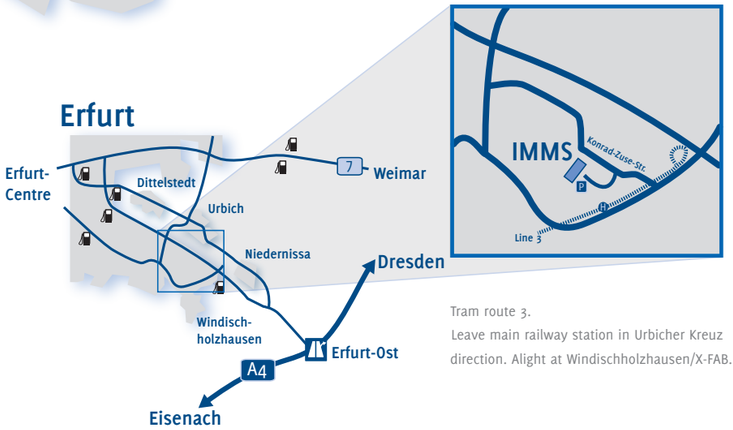

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WE CONNECT IT TO THE REAL WORLD.

Contents

4 Foreword

6 The IMMS Research Strategy
8 Collaborating with Ilmenau University of Technology

9 **Testimonials**

Young Blood, Events and Milestones
14 IMMS and the encouragement of young academics
18 Events and milestones
24 Trade fairs, conferences and workshops with contributions by IMMS

Staff at IMMS present their work:

26 **3DNeuroN –**
3D interface with the brain

29 **GreenSense –**
enabling technology for smart, resource-efficient, energy-efficient sensor networks

32 **EFSUES –**
energy-efficient airports

35 **ANUBIS –**
solutions towards energy-efficient production

38 **MEMS quality assurance**

41 **SFB 622 –**
on the track of the nanometre

44 **MEMS-T-Lab**
a new test lab for MEMS-based micro systems

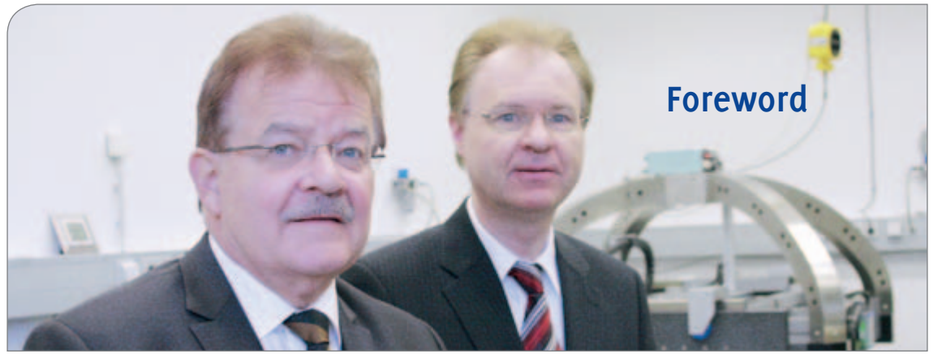
Proof through Facts and Figures
48 Facts and Figures

49 Organigram
50 Scientific Advisory Board
50 Supervisory Board

51 Lectures, lecture series
51 Publications 2013

Abbreviations

ADC *Analog-to-Digital-Converter*
ASIC *Application-specific integrated circuit*
BMBF *Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research)*
BMWi *Bundesministerium für Wirtschaft und Energie (Federal Ministry of Economic Affairs and Energy)*
BVMW *Bundesverband mittelständischer Wirtschaft (German Association for Small and Medium-Sized Businesses)*
CMOS *Complementary metal-oxide-semiconductor*
DFG *Deutsche Forschungsgemeinschaft (German Research Foundation)*
DLR *Deutsches Zentrum für Luft- und Raumfahrt e.V. (German Aerospace Centre)*
EDA *Electronic Design Automation*
ERDF *European Regional Development Fund*
EnOcean *energy harvesting wireless technology*
FE *Finite Elements*
FTE *Full-time equivalent*
FTSP *Flooding Time Synchronisation Protocol*
IC *Integrated Circuit*
ICT *Information and communications technology*
ISO *International Organization for Standardization*
KNX *Fieldbus, worldwide standard for all applications in home and building control*
LNA *Low Noise Amplifier*
MEMS *Microelectromechanical systems*
MINT *Mathematik, Informatik, Naturwissenschaften und Technik (Maths, Computer Science, Natural Sciences and Technology)*
NPMM *Nano Positioning and Measuring Machines*
OLED *Organic light-emitting diode*
QI *Inductive power standard*
RF *Radio frequency*
RFID *Radio-frequency identification*
RMS *Root Mean Square*
RWTH *Rheinisch-Westfälische Technische Hochschule (RWTH Aachen University, Germany)*
SFB *Sonderforschungsbereich (Collaborative Research Centre of DFG)*
SME *Micro, small and medium-sized enterprises*
TERENO *Terrestrial Environmental Observatories*
TU *Technische Universität (University of technology)*
VDI *Verein Deutscher Ingenieure (The Association of German Engineers)*
VGA *Variable Gain Amplifier*
wM-Bus *Wireless meter-bus for the collection of consumtion data*
ZigBee *Industry standard for wireless networks*



Foreword

As research partner to academia, IMMS straddles the gap that might otherwise exist between pure and applied science, particularly for innovative applications. Playing a strategic partnership role, it makes the early, targeted research for the development of microelectronic products, systems technology and mechatronics available to industry, in particular SMEs. It can often take between five and ten years for scientific research outcomes to be transferred into mass production, and this vital task cannot be undertaken in the context of the pure research conducted at universities. Despite this, if an idea is to be taken from the drawing board through to the market launch, the task is sine qua non. Such transfer from pure research to its application is expensive in human and other resources. In supporting the transfer, IMMS builds a bridge between science and industry. The bridge is rendered stable by the Institute's close cooperation with Ilmenau University of Technology (TU) and its industrial partners, and also strengthened by IMMS' position in organizational networks and clustered centres of excellence and by its policy of encouraging new talent. Joint solutions are found and worked on so that they become new products which will give all the partners a competitive edge. SMEs, in particular, can rarely afford this bridging activity from their own resources, for they lack not only the necessary research capacity, but also the financial strength to undertake such a huge task. In Trendatlas 2020, a consultative document commissioned by Thüringen, and in Thüringen's official research strategy, this bridging between science and industry is highlighted as one of the central issues and underpinned with an agenda for action. The IMMS field of influence is such that it contributes significantly to the competitiveness of Thüringen's industry, strengthening the networks and renewing the human resources.

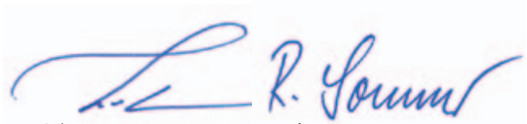
The IMMS motto, "Wir verbinden die IT mit der realen Welt", which emphasises the need to connect IT to the real world, stands for the Institute's intention to meet these challenges and is reflected not only in the sharpened 2013 **research strategy** described in the first article of this annual report but also in the associated projects. The Institute possesses an impressive spectrum of experience and knowledge which is being ever extended. In it, theory and practice are bound together, a principle which is a strong foundation for the fulfilment of the Institute's task, both now and – even more – in future. The research and development fields to which IMMS is contributing its know-how and practising interdisciplinary collaboration are those of high-precision, energy-efficient comprehensive systems for use in automation, environmental engineering, transportation, semiconductor manufacture, medical technology and life science. IMMS is an indispensable partner in the development of applications from the enabling technology which is capable of extension to a number of industrial fields, such as those of communications, measuring and control technologies and micro-/nano-engineering. For all of these, the Institute works out total solutions for the entire value-added supply chain right through from the original idea to the transfer into serial manufacture. This strategy matches the requirements of internationally relevant future planning as formulated by the Federal German government (among others) in its high-tech strategy. The plans demand high and varied ability to cope with complex systems (as noted in the research strategy). IMMS is also engaged in the German ICT2020 programme, where it is building on its systems competence and making this accessible to its partners, especially Thüringen's SMEs. Likewise, IMMS' research strategy matches very well the focal points of Thüringen's policies for science and industry. The research work being currently conducted in the context of the projects also reported on in this document, GreenSense, ANUBIS and EFSUES, is another powerful contribution from the Institute, supporting "green", energy-efficient manufacturing and resource consumption. Such concerns are those which are funded by, for example, the Thüringen GreenTech programme as coming under the heading of energy, resource and materials efficiency.

Turning from research strategy to **partnerships**: here, the main pillars are the working partners found in industry, in the national and international research scene and in Ilmenau University of Technology. IMMS is an affiliated institute of the TU, cooperating at present with 28 of its departments. There are joint projects, such as MUSIK, GreenSense, KOMPASSION and 3DNeuroN and the German Research Council project "Nanopositioning and Nanomeasuring Machines" (SFB 622), for which the two partners combined their technological competence again in 2013 and spurred each other on. Wherever possible, the Institute draws in any technology available in the region to benefit its research, thus contributing to the networking between enterprises counselled in the Thüringen Trendatlas and intended to exploit to the full the innovation potential there is in SMEs. For many years, the Institute has been active in initiating and forming cross-industry, cross-region and cross-country clusters. Examples in Thüringen are ELMUG (standing for electronic measurement and instrumentation in Thüringen), MNT (micro- and nano-technology in Thüringen), OLAB (OLED industrial lighting applications) and OptoNet Thüringen. Beyond Thüringen, IMMS has become involved with sensor issues in the Sensor Science Association, the professional group supported by the AMA (German sensor manufacturers), among other organisations. The Institute offers regular workshops in the field and helped organise and conduct the Sensor Trends 2014 study as a member of the academic board. IMMS engages in the applications working parties of Silicon Saxony e.V., one example being the Cyber-physical systems group, to the founding of which it was an active contributor. The Institute is also a member of the "edacentrum" and involved in electronic design automation, EDA. This it develops and uses as a key technology in microelectronics and microsystems. Jointly with Ilmenau University of Technology, IMMS acts as Lead Institution in the international organisation called Cadence Academic Network, Cadence being one of the market leaders worldwide in EDA software development and supply.

IMMS takes very seriously its duty of **encouraging the scientists of the future.** The career notes provided by young academics in this report are themselves examples of the way the Institute supports interns, BSc, MSc and PhD students and student staff.

The 87 members of staff at IMMS were again busy in 2013 progressing many new ideas and **projects** which were intended as initial research for use in later applications and as the means of helping industry to bring original ideas to a marketable stage. In their work they carried out research into microelectronic sensors and actuators that may in future intervene to enable damaged tissue in the central nervous system to repair itself. Another innovation is IMMS' development of wireless sensor networks and smart, energy-efficient and energy-autonomous sensor systems, which in combination will optimise industrial processes, making them kinder to the environment. Likewise, they will enable airports to be managed with greater safety and energy savings. So that semiconductors and the products for life science and biotechnology can in future be produced with precision down to the nanometre, the institute has developed some highly accurate mechatronic drives. IMMS has extended its instrumental infrastructure to enable it even better to test and characterise the MEMS it develops. In addition, it has refined a procedure developed in-house which allows the functionality and quality of MEMS to be monitored throughout the manufacturing process. This annual report demonstrates the intense research work which was necessary for this and for many other IMMS developments.

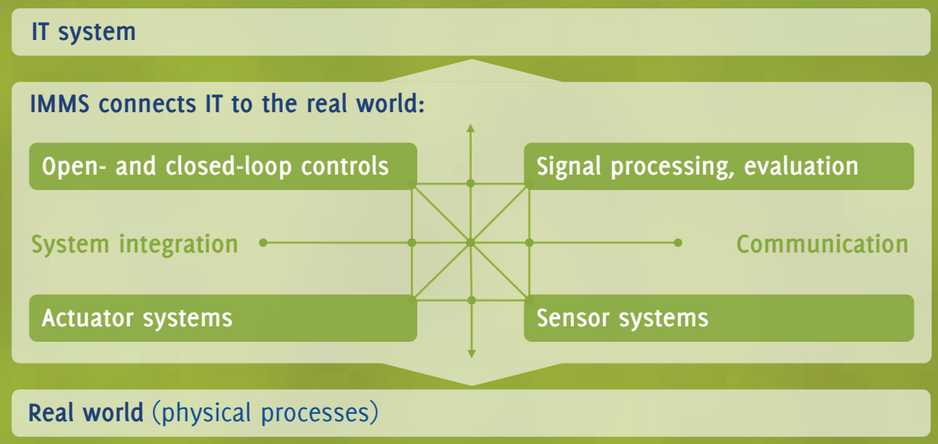
At this point it is appropriate that we express our **sincere thank**s to the "Land" of Thüringen in the name of the entire IMMS team, for it is only with regional financial assistance that our work can be continued. Our thanks also go to the Supervisory Board and the Scientific Advisory Board of IMMS for their constant encouragement, advice and support. Thank you, too, to Ilmenau University of Technology – for the outstanding collaboration which is not only a great enrichment of our work but produces the effects of synergy by forging links between the research subjects of both establishments and across a variety of scientific disciplines. Our thanks also go to our business partners, supporters and friends and to all the people who encourage us in our efforts. Most of all, nothing would be possible without our creative and committed thinkers. We should like these staff and students to accept our thanks for contributing their expertise, individual skills and knowledge so constructively and reliably to the Institute's work and for involving themselves in our shared future.



Dipl.-Ing.
Hans-Joachim Kelm

Prof. Dr.-Ing.
Ralf Sommer

The IMMS Research Strategy:



“We connect information technology to the real world”

The transfer of scientific research results into industrial products and services is usually a complex and lengthy process with a lead time of several years. With a focus on strengthening the national and international competitiveness of small and medium enterprises (SMEs), our mission is to enable our customers to bridge the industrialization gap for a broad range of innovative products and technologies that benefit from the integration of electronic and mechatronic systems solutions. To be prepared for the challenges arising from emerging technologies and future applications, we constantly align our strategic activities with current global R&D trends.

Major R&D fields with particularly high potential for innovation are energy, mobility, transport, logistics, health care and mechanical engineering. The main innovation drivers in these areas are the current and future societal challenges regarding our environment, health, security, mobility, communications and automation. Modern information and communication technologies (ICT) and their interaction with physical processes in the real world play a key role on the way to solving these challenges. Under the motto “We connect information technology to the real world”, IMMS concentrates its R&D activities on enabling and optimizing this interaction for a wide range of cyber-physical systems (CPS) in application areas such as Industry 4.0 or personalized health care.

Connecting IT applications to the real world requires smart systems solutions that involve digital data processing capabilities, mechanical and electronic sensor and actuator components, and links to a common data communication infrastructure, e.g. the Internet. The members of our R&D staff analyse the physical conditions and processes of future systems, such as machines or industrial plants, and map them onto IT applications. These results are integrated into our system designs, based on which we support our partners in developing and optimising complete solutions from the concept stage until prototype production. We perform R&D on integrated sensor and actuator components, signal processing, and embedded control and automation systems. In addition, we offer system integration services for electronic and mechanical hardware as well as software and networking components. IMMS develops and optimises not only all the individual system elements, components and circuits, but also the communication among those elements and between them and their environment. Specifically, we focus on the following R&D topics.

Sensor and actuator systems:

- energy-efficient sensor and actuator systems
- micro-electronic and micro-mechanical sensor and actuator systems
  . electronics for biomedical and life-science applications
  . high-temperature electronics
  . MEMS
- mechatronic actuator systems

Open- and closed-loop controls:

- application-specific open- and closed-loop controls
- real-time control systems

Communications solutions:

- energy-efficient wireless sensor-actuator networks

Signal processing:

- embedded hardware and software platforms
- high-performance sensor signal processing systems

System integration:

- optimisation of open-source software and operating systems for industrial applications

Using simulation and measurement, IMMS ensures system reliability and robustness right through from the IC to the complete system.

There are articles in this annual report that illustrate the great competence IMMS has systematically developed over the years in all these fields. One example is in the SFB 622 project where the mechatronic actuators (including open- and closed-loop control) have set new standards for nano-technological drive systems. The articles on ANUBIS and EFSUES present various solutions in the spheres of signal processing, communications and systems integration. The know-how applied in designing micro-electronic sensor systems is illustrated in the articles on the GreenSense and 3DNeuroN projects. The pages on MEMS-T-Lab and QA for MEMS using vibrometry take as their subject the instrumental verification of methods and prototypes developed at IMMS.

Biotechnology as an example of pioneering research

The research at IMMS is to be expanded in future to meet the needs of a strategic field where there is much growth, biomedical technology and life science. Here, the Institute is contributing, inter alia, its long-standing know-how in the fields of opto-electronics and analogue/mixed signal circuit design with a view to developing integrated systems for bio-signals susceptible of optical detection and to developing bio-compatible electronics like the ASIC successfully designed for retinal implantation in a project concluded as early as 2011.

IMMS is aiming also to speed up, simplify and reduce the costs of in-vitro diagnostics and individualised medical care by applying micro-electronic solutions. This will involve finding new ways to combine the advantages of micro-electronics, mechatronics and systems engineering with current bio-analytic methods. It is a particular intention to expand the various analysis options which are at present open to research partners and to run continuous or simultaneous testing.

New staff has been taken on at IMMS to contribute knowledge of bio-signal processing and biomedical technology so that the Institute can systematically expand the knowledge it already possesses in this field.

Collaborating with Ilmenau University of Technology

Being an affiliated institute of Ilmenau University of Technology (TU), IMMS benefits from networking with the university while the TU benefits from the Institute's close relations with industry.

The TU Departments with which IMMS co-operated actively in 2013 were 28 in number, from the broad fields of electrical and mechanical engineering, computer science and engineering, automation, mathematics, media and communications, while the academic subjects addressed included high-precision positioning and measuring machines, biomedical technology, sensors for monitoring of high-temperature processes, and RF technology for satellite-aided navigation. In parallel, the Institute operates in a close industrial network, in the form both of industrial clusters and of regional and national innovatory networks. These fields include automotive engineering, microtechnology, microelectronics and optics. Valuable impetus is given by the groupings. They are the chance to pool skills, use partners' technology and develop joint marketing strategies.

Joint research projects

Collaboration with the TU took place in many ways, among them the German Research Council project "Nanopositioning and Nanomeasuring Machines" (SFB 622) and the GreenSense and 3DNeuroN projects. The present IMMS report, for 2013, includes articles which illuminate these research contributions in close detail. In the context of ThIMo (the Thüringen Mobility Innovation centre) IMMS is also co-operating in the PORT research group (PORT stands for Powertrain/radio train), which, like GreenSense, will be a powerful contributor to "green" manufacturing and resource consumption.

In the DFG (German Research Council) project named MUSIK, IMMS researchers and members of the TU are working in partnership on the amplifying, controlling, oscillating and switching properties of MEMS (microelectromechanical systems) in order to design MEMS in conjunction with the electronics for radio frequency circuits and systems. The aim is to achieve a universally applicable design method which will remove the technological discrepancy which currently exists between conventional MEMS design methods and those for circuit design which are model-based and computer-aided and are used for ASICs (application-specific integrated circuits).

The Institute and the University have together produced in the KOMPASSION project a receiving unit which is only a quarter of the size of a conventional group antenna but has the same number of individual elements. The receiver front end circuit for the antenna was designed and created by IMMS. From the start of 2014, the 3-year-long follow-on project, KOSERNA, will see an industrial prototype developed that contains an even more robust and accurate receiver. For this, too, the TU has subcontracted the work on the front end circuit to IMMS, who will also transfer the new designs to a second frequency band.

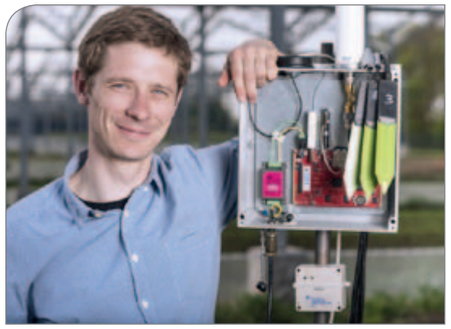
Joint encouragement of young academics

One way, but not the only way, in which IMMS complements the TU's teaching is the challenging industrial placements it offers, as described later in this report. Another way is that various lectures and seminars are given by IMMS staff. Professor Sommer himself is, in his teaching role, involved not only in the AG Lehre (national working party on teaching) but also, together with IMMS, in the Basic Engineering School that Ilmenau University of Technology has now established. The School is intended to make engineering degrees more attractive to potential students, particularly by using new methods of teaching and learning geared to students' needs, and by making practical activity part of the courses. The bottom line will, it is hoped, be a reduction in the engineering student drop-out rate because of better-anchored knowledge and raised motivation. IMMS is both trainer and motivator, offering not only highly practical and relevant placements but illuminating guided tours.

There is a yet younger generation receiving the attention of IMMS and the University: at Kinderuni (Children's University) the more than 650 students aged between 8 and 12 heard a lecture entitled "On the track of music – from the gramophone to the mp3 player" in which IMMS gave a practical demonstration with many interactive games to show how music and signals can be stored and processed in both analogue and digital form.

Right:
KOMPASSION project staff from IMMS and the Ilmenau University of Technology RF and Microwave Research Laboratory, preparing to analyse interference suppression in the University's anechoic chamber. Photograph: IMMS.

Funding for the project has come from the Space Agency of the German Aerospace Centre, using resources (reference 50 NA 1009) from BMWi, the federal German ministry of economics and technology, as decreed by the federal German parliament.



Dr.-Ing. Jan Bumberger, researcher at the Helmholtz Zentrum für Umweltforschung – UFZ. Photograph: André Künzelmann, UFZ.

Dr.-Ing. Jan Bumberger, UFZ

”We needed to solve a problem for the GCEF research project, Global Change Environmental Facility – to find a way of collecting data over a wide area at a minimum price with minimum disruption on installation: data on air and land humidity, incidence of light, and temperature. IMMS’ many years of experience in wireless detection sensor networks were a significant help to us. They had a platform which they further developed so that we were able to transmit the data required to TERENO, the European environmental data base, indeed even more than the basic data. With IMMS we were able to find hardware and software solutions of particular importance to long-term recording of open-air data. In the open air, the sensors have, of course to be weatherproof, but also it is necessary to position the nodes correctly, to provide long-term and flexible electricity supply as well as energy-efficient operation. The IMMS researchers adapted their solutions seamlessly to our demands even when we changed them on the basis of experience, and, what is more, they coped with new demands on our part. For example, one of the plug-in modules they developed for our project will act as a location-finder using GPS; and memory that they integrated into the sensors will act as back-up data storage if communications break down. We are more than satisfied with the solution and have been able to use the platform with great flexibility in a variety of situations. Collaborating with such a committed partner was great. We are looking forward to a resumption at the earliest opportunity.“

www.ufz.de

Dr. Joachim Metter, managing director at SMI GmbH. Photograph: Flughafen Erfurt-Weimar.

Dr. Joachim Metter, SMI

”In the EFSUES project together with IMMS we developed a new monitoring system for small and medium-sized airports that enables aeroplanes, vehicles and people to be so certainly detected if they are on the apron that, whatever the weather and whatever the visibility, operations can continue efficiently. It was not only thanks to its know-how in radio communication at 868 MHz and its expertise in systems development for real situations that IMMS was an ideal partner for us, but also thanks to its communications platform, from which new solutions might be launched. With its detector nodes for the wireless network and the receiver module for our newly developed antenna array, the Institute produced excellent prototypes in which little is lacking before they will be a marketable product. The sensor nodes are already small, lightweight and long-lived – features which fully meet the highest demands of the customer.

The colleagues in IMMS worked extraordinarily well in harness with us, reacting swiftly to our every query and constantly improving the developing solutions with their inventive ideas. We therefore look forward with confidence to the tests which are planned on airports in Ukraine and Poland once the project is complete in 2014. It is our expectation that the tests will go well and that product development will follow right away. We are also aiming at further collaboration with IMMS, this time on sensor networks for the field of ambient assisted living.“

www.smi-online.de

Dr.-Ing. Ralf Stephan, Akademischer Oberrat (senior lecturer), RF and Microwave Research Laboratory, Ilmenau TU. Photograph: Ilmenau TU.

Dr.-Ing. Ralf Stephan, TU Ilmenau

“The RF and Microwave Research Laboratory at Ilmenau University of Technology has been working together with IMMS on a project to develop compact satnav receivers that are highly reliable. The project is named KOMPASSION and involves new concepts and technologies which are based on adaptive group antennas made up of individual elements in close vicinity to each other. The receiving unit developed is only a quarter as big as a conventional group antenna but has the same number of elements and demonstrates the applicability of the jointly designed antennas and receivers. The multi-channel, low-noise analogue frontend was developed by IMMS. It forms the link between the group antenna and the digital evaluation electronics.

The IMMS expertise in RF circuit design, in the actual implementation of the circuit and in measurements to verify the RF properties was particularly important here. As our partners, the Institute’s staff applied themselves consistently and with understanding of the whole system reaching well beyond the ASIC they had themselves developed. The scientists on both sides achieved valuable mutual support and comprehension, which was of great benefit.

As a result, there was not only a successful demonstration the functioning of the satnav receiver system but, furthermore, the TU accepted IMMS’ tender for a subcontract in the KOSERNA project which is to concern itself with the improvement and development of the design for industrial purposes.”

www.tu-ilmenau.de/it-hmt/

Dr.-Ing. Gotthard Weißflog, project manager of the OLAB network, Jena. Photograph: Lutz Prager.

Dr.-Ing. Gotthard Weißflog, OLAB

“Organic light-emitting diodes, OLEDs in short, open the door to lighting with many advantages: it is independent of inflexible luminaires, is capable of colour and brightness control, heats up very little, needs only shallow depths for installation and is robust. OLEDs represent only a niche market at present because they are costly and their energy efficiency has yet more scope for optimisation. IMMS is involved in the OLAB network, an association of thirteen Thüringen companies, which aims to open up OLED technology to the mass market. During their work on new OLED applications in the industry, the thirteen are focussing in particular on image processing, microscopy, medical technology and illumination. Other fields where the prospects are bright for OLEDS are the automotive industry, architecture and furniture design. IMMS was a moving force in the launch of the EROLEDT project, which sees the Institute cooperating with three close partners in the network on a unified energy-efficient and cost-efficient OLED system. IMMS' role is significantly to advance the OLED technology, not least by contributing its genuine expertise and its long experience in the development of opto-electronic ASICs. The microelectronic driver developed by IMMS ensures that the OLEDs are supplied with electricity in an efficient manner but without the use of an external mains adapter. The driver also enables brightness control and permits networking with a central control unit. IMMS is a vital partner in the OLAB network, bringing Thüringen closer to the goal of setting up an early factory to meet the coming needs of this growth market.“

www.oled-olab.net

Dr. Olaf Brodersen, manager of the AMOS section, CiS research institute (CiS Forschungsinstitut für Mikrosensorik und Photovoltaik GmbH). Photograph: CiS.

Dr.-Ing. Jens Kobow, managing board assistant, Supracon AG Jena. Photograph: Gebhardt.

Dr. Olaf Brodersen, CiS

"As part of the BMBF joint project named KD Optimi, IMMS as subcontractor to CiS developed three customised integrated circuits, with which we at CiS hope to extend our range of optoelectronic microsystems products for industrial applications. The IC produced by IMMS will, because of its transimpedance amplifier (adapted to the CiS photodiodes), evaluate the flow of current in individual photodiodes or small arrays, so that it can be used for variety of applications. The LED driver ASIC developed by IMMS has extended our ability to stabilise and control the brightness of LEDs. The third circuit provided by IMMS is an evaluation IC for a silicon photomultiplier and will enable tiny light signals to be evaluated, even down to single photons.

The cooperation with IMMS ran extremely smoothly. The colleagues were spot on and worked with efficiency, so that they produced the designs for the first two ICs within the shortest possible time and passed the design over for manufacture. Even in prototype form, the ASICs produced fulfilled their function, as IMMS was able to confirm in its measurements. Both ASICs are being installed by CiS, both operate reliably and both have been presented by us to knowledgeable customers at trade fairs such as COMPAMED 2013. At the end of 2013, it was the turn of the newest Optimi IC to be tackled: IMMS sent this on to the manufacturing stage at the beginning of 2014. As the project has gone so well up to now, we fully expect that this ASIC, too, will enjoy the same success as the first two which were developed. Our aim is to collaborate even more intensively with IMMS in the future."

www.cismst.org

Dr.-Ing. Jens Kobow, Supracon

"We at Supracon are most grateful that the TESCA project has gone so well. It involved the development of a scanning device for a next-generation terahertz camera; our partners in the project were IMMS in Ilmenau and the KVB at Chemnitz University of Technology. The new system makes it possible to carry out safety checks over even quite long distances (5–40 m). The familiar solutions used to date in airports operate only over shorter distances.

IMMS designed and created an actuator for the system under investigation which includes in its design special voice coil actuation, energy storage based on magnetic springs and an adaptive control algorithm. Supracon's own capacities in the resolution of such a sophisticated technical problem were very much complemented by IMMS' long experience in the development of highly efficient drive systems. Currently, discussions are taking place on how to implement the product under development for a customer's system which will require some adaptation of the new drive. We are aiming to continue the sort of highly efficient, targeted cooperation that we have had so far with IMMS."

www.supracon.com

Right:
Dr. Christoph Schäffel, Head of Mechatronics at IMMS giving a guided tour of the Mechatronics Lab to Basic Engineering School visitors. Photograph: IMMS.

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WE CONNECT IT TO THE REAL WORLD.

YOUNG BLOOD, EVENTS AND MILESTONES

IMMS and the encouragement of young academics

Yulia Lapteva testing wireless sensor networks in the automotive environment while working on her MSc dissertation, supervised at IMMS. Photograph: IMMS.

It is one of IMMS' highest priorities to bring on the new blood in science. Again in 2013, the research staff at IMMS has been active in pursuit of this goal, inspiring and supporting undergraduate and Master's students in particular. School pupils, too, have been given insight into the work of IMMS by means of events and internships or by having their coursework supervised by IMMS professionals. It is, above all, the students at Ilmenau TU who come to the Institute, but they are joined by students from other universities at home and abroad in receiving a knowledge of methodology soundly based in theory and in linking this to its practical use. Young engineers from a variety of disciplines – biomedical, electrical or automotive, computer or mechanical engineering, mathematics, mechatronics and physics – are able to work on exciting scientific problems at IMMS and all receive individual supervision. The Institute also offers training courses and guided tours of the establishment. In all, the year 2013 saw 17 students working at IMMS either as interns or student research assistants or in association with the dissertations they were preparing for their BSc, MSc or German "Diplom". The fact that the Institute networks so closely with industry provides the new generation of scientists with the opportunity to work on subjects of practical relevance where the results really matter.

IMMS has its own internationally competitive infrastructure, fully meeting industrial norms, supporting the design of and experimentation on electronic and mechatronic systems, and underpinning its research work and the preliminary systems qualification processes. The fact that we have so high a proportion of students from our own TU is an indication that our intensive pure research efforts 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. There are other ways in which IMMS supports and stimulates new academic blood: one is the Scientific Seminar, at which undergraduate and doctoral students present their work and any issues for discussion. The intense and lively academic exchanges initiated in this way cross the subject borders, encouraging new connections to be made and new ideas to be considered.

Dipl.-Math. Yulia Lapteva, M.Sc. – first to obtain the dual Russian-German MSc

In 2013, Ms Lapteva became the first student to achieve the dual MSc offered under the TU Ilmenau's SPITSE scheme, with her dissertation on "Modelling and Simulation of Propagation Conditions for Wireless Sensor Networks in Automotive Environments". The scheme is a strategic alliance between the engineering faculties of the TU, the Moscow Power Engineering Institute and the National Research University of St Petersburg. While she was at the Ilmenau TU, Ms Lapteva spent almost a year with IMMS, which included a four-month internship and six months of MSc work. In her time at IMMS, she was involved in activities which were to progress two central research concerns of the Institute, Industry 4.0 and Electromobility.

The internship was spent on a thorough study of how wireless sensor networks function in a technical, largely metallic, environment. The knowledge she obtained was then put to use in current research projects. It enabled wireless nodes to be placed in the best possible position for their propagation behaviour in metallised areas of the networks so that resources were conserved while the parameters of the surroundings were being recorded. The knowledge was also valuable as the basis of Ms Lapteva's dissertation for the MSc. The work for this was to create a simulation model in Castalia, a wireless sensor network simulator which is based on the OMNeT++ platform. The model describes the propagation of radio waves in this type of environment and Ms Lapteva carried out measurements which validated it. The model is thus now available to the Institute for future use in automotive sensor network applications for new research and development projects. Ms Lapteva found that she had her dissertation closely supervised by her fellow-researchers, and, furthermore, that she was able to call on the whole IMMS infrastructure in her work and especially the wireless sensor nodes which had been developed in house, not to mention the measurement software programs available and a desk of her own.

Now she is reading for a PhD at the UFZ Centre for Environmental Research in Leipzig. The UFZ is working on systems solutions involving wireless sensor networks developed by IMMS. Following up the knowledge she gained while she was with us at IMMS, Ms Lapteva is using the networks while tackling the subject of environmental monitoring.

Raiko Pevgonen, MSc., researcher in Microelectronics in the sensor and actuator electronics team. Photograph: IMMS.

Raiko Pevgonen, M.Sc.

"After I had had a year abroad at HFU, Hochschule Furtwangen University, as an Erasmus student of Microsystems Engineering and had completed my BSc at Tallinn University of Technology in Estonia, I was searching for a subject for a Master's dissertation of relevance to real life that would send me into new fields while returning me to Germany. The search led swiftly to IMMS. I joined the 'KOMPASSION' project research team, which was at that time concerned with finding new microelectronic solutions to make the adaptive group antennas needed for satnav interference mitigation more compact so that they could be used in mobile devices. It is a source of pride to me that my dissertation for the MSc on Design of a Mixer for a GPS/Galileo Receiver was an element of this highly successful project, which finished in 2013. The ASIC that the KOMPASSION team developed contains a mixer which I designed to down-convert the frequency of the satellite signal, notwithstanding the fact that I had had hardly any experience with radio-frequency circuitry before I started. I was given the freedom to steep myself in the subject (a considerable task, of course) and to develop my own ideas. At the same time, I was guided through the process to enable me to keep to deadlines and fulfil all the demands of circuit design. It was an exciting time and I learnt a great deal. Having obtained further experience as a design engineer at Alpha Microelectronics GmbH in Frankfurt-on-Oder I seized the chance of returning to IMMS in 2013. There was a job going at the Institute in the design of integrated sensors and actuators, which was exactly the subject I had specialised in at Furtwangen. So now I am working in the MEMS2015 project which is developing coherent design methodology for microelectronic and micromechanical components. My current work in this project is twofold, the design of a cantilever frontend and the signal processing circuitry for an acceleration sensor front end.

Just as it was at the beginning, it is still tremendous fun to go off in search of new solutions and to have the chance to advance the state of the art. The flexible working hours also suit me very well, as they mean that my creative phases can be very productive. Last but not least, just as was the case when I was a student, I am being well looked after in an environment which enables people to move their shared ideas forwards well outside of hierarchies. The setting is one where I have found real friends among my colleagues."

Georg Gläser, MSc, researcher in Microelectronics in the High Temperature Electronics team. Photograph: IMMS.

Georg Gläser, M. Sc.

"My first contact with IMMS was when I went to the lectures of Professors Sommer and Töpfer and Dr. Hennig while I was reading for my BSc in Electrical Engineering and Information Technology at Ilmenau University of Technology (TU). Then, in my research seminars, I was directly involved, both during the BSc and the MSc. IMMS had developed the drive for the terahertz scanner and I was working on a multiplexer design for it. The fact that the Institute focuses on a range of systems (analogue components in ASICs as well as software itself) suited me very nicely because signal processing and electromagnetics were what I had studied and I could keep the connection with circuit engineering. I was given excellent supervision during my industrial placement on microelectronics at IMMS. I was fully involved in a research project to create a high-temperature measurement system with digital signal processing. It was thus the logical next step to write my BSc and MSc dissertations here. The BSc dissertation was a basis for my MSc work, in which I was able develop an idea I had on how to improve SystemC simulations at the transaction level and to put it into practice from beginning to end. My research results contributed directly to the GreenSense research project and are being used again in the EROLEDT project.

Thanks to regular discussion with the people who later became my colleagues, and thanks to the presentation of my interim results in the IMMS Scientific Seminar, I was able to reflect theoretical principles in practical examples and obtain real-world experience. Not only that, but Professor Sommer gave me the opportunity to do some teaching at Ilmenau University of Technology, holding seminars on circuit engineering. The seminars were not only great fun to give, but brought me much new knowledge as well as general experience, all of which I can put to good use at IMMS.

As a post-graduate I have been able to remain with the Institute and am currently working in the microelectronics department where I am mainly involved with system architectures and their evaluation, which means I am continuing with development work for which I laid the foundations in my degree courses. All the knowledge I am acquiring is building up a base for my doctoral studies on analogue coverage.

What a good choice I made in joining IMMS, not only academically but personally. The atmosphere in our team, the international stage on which we play and our constructive discussions constantly contribute to my personal and professional progress. I really enjoy working at IMMS and would make the same choice of job all over again."

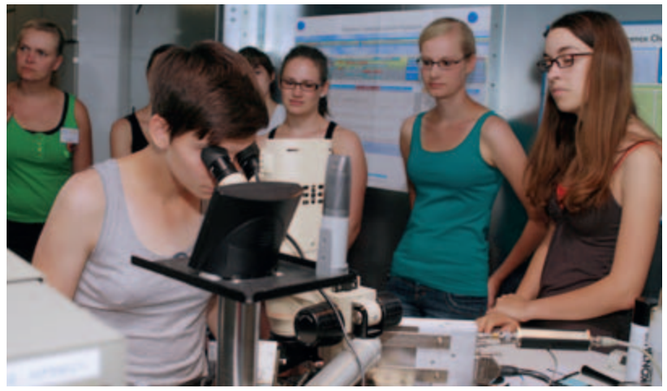
Events for young academics supported by IMMS

Girls' Day

Three of the female researchers at IMMS accompanied schoolgirls from the fifth year of each Ilmenau Gymnasium (secondary school for the academically able) on Girls' Day, 25 April, 2013 on a voyage of discovery through the Institute. By playing interactive games and by experimenting, the pupils were able to find out what types of vibration there are, how to make them visible, how they are used and how they can cause damage. On visits to laboratories, the visitors were also given an insight into how researchers' work influences everyday life.

Lecture Series at Ilmenau University of Technology

Two student organisations at the Ilmenau University of Technology, sci e. V. and ProWiWi e. V., have established a tradition (as part of the summer semester Ringvorlesung series) of organising lectures which are given by representatives of industrial companies in Thüringen on the subject of their daily business. These events are an opportunity for the students to get an insight into real-life situations and for the speakers, the students and their professors to exchange notes and knowledge. IMMS once again supported the scheme in 2013. Dr. Wolfgang Sinn, Strategic Marketing Manager, spoke on "Industry 4.0 and the future of productive labour", providing a glimpse into collaboration between research and industrial production and stimulating discussion on the conflict between complexity and core competences in which innovative enterprises can find themselves; also on the challenges and opportunities inherent in future industrial policies.



MINT pupils in the Nano-Orientation Academy visiting IMMS during the Summer Courses at Ilmenau University of Technology. Photograph: IMMS.

Sensors being tested on Girls' Day at IMMS. Photograph: IMMS.

The Summer University at IMMS: MINT girls-pupils looking for a future

On 22 July, 2013, IMMS offered 16 girls participating in Ilmenau University of Technology's Summer University an introduction to the work and research carried out at the Institute. The pupils, aged between 16 and 19, travelled to Ilmenau from every part of Germany. All were at some stage of their course for the Abitur (the German examination qualifying for University entrance) and had the MINT subjects as their focus. MINT is the neat German abbreviation for Maths, Computer Science, Natural Sciences and Technology. In the "Academy for Nano-Orientation" they learnt how IMMS connects to the field of nanotechnology and what job prospects exist in that field. They had lectures and guided tours through the laboratories, discovering the world of the semiconductor and the trend towards ever greater wafer diameters and ever tinier components. They were treated to a striking demonstration of how a laser Doppler vibrometer assists in investigating the mechanical features of micrometer-size structures without any contact. Their visit to the drive laboratory revealed the challenges that must be met if drives are to be developed for machines which work to an accuracy of nanometres. The girls made use of the discussion session to engage in conversations with their hosts, learning yet more about work routines for women researchers.

Basic Engineering School and Kinderuni

As a teacher, Professor Sommer is involved not only in the AG Lehre (national working party on teaching) but also, together with IMMS, in the Basic Engineering School that Ilmenau University of Technology has now established. The School is intended to make engineering degrees more attractive to potential students, particularly by using new methods of teaching and learning. The bottom line will, it is hoped, be a reduction in the engineering student drop-out rate because of better-anchored knowledge and raised motivation. IMMS is both trainer and motivator, offering not only highly practical and relevant placements but illuminating guided tours (there was one in April 2013) and numerous subjects for students on placement to follow.

There is a yet younger generation receiving the attention of IMMS and the University: the Kinderuni (Children's University) again took place in November 2013. The more than 650 students aged between 8 and 12 heard a lecture entitled "On the track of music – from the gramophone to the mp3 player" which gave a practical demonstration with many interactive games to show how music and signals can be stored and processed in both analogue and digital form.

Support for coursework

IMMS researchers provided mentoring for pupils from the special mathematical and science classes in the Albert Schweizer Gymnasium of Erfurt who have to do coursework known as their Seminarfacharbeit. For this, they took radio wave propagation in the 630m frequency band as their subject and developed receiver, transmitter and antennas. It was their aim in the project to open up new areas of application in the messaging field and to make profitable use of the features and advantages that the lower medium-wave range offers for radio communication. The pupils entered their results for the "Jugend forscht" scheme, a national schools research competition.

Events and Milestones

Project Highlights

Continuing BMBF MEMS 2015 project positively reviewed

MEMS (Micro-Electro-Mechanical Systems) are one of the keys to innovative manufacture of plant and equipment. As such, they are an element of the Industry 4.0 strategic project. It has now become necessary to work out new methods of designing MEMS so that today's industry can be supplied with powerful, new sensor and actuator systems, which is the purpose of IMMS' involvement in the MEMS2015 industrial research project of the BMBF (the German Ministry of Education and Research). This project brings together on the one hand Bosch, X-FAB, Cadence, TETRA, Carl Zeiss and Coventor, who are semiconductor manufacturers, EDA suppliers and EDA users, and, on the other, our Institute, the University of Bremen and TUM (the Technische Universität, München). The task of these agencies goes further than that of producing processes and process data for MEMS. The real challenges lie in the merging of design procedures for micro-electronic circuits and micro-mechanical structures, so as to achieve a comprehensive design system for sensors and actuators in combination. And, even further, MEMS have to be modelled for the development of the end product, closing the gaps between semiconductor and sensor manufacture and the end use, gaps which have so far stood in the way of wide use of MEMS in fields relevant to the professions and to industrial safety. The tried and trusted principle of modular design has to be transferred from the methodology used in micro-electronics onto MEMS and onto mechanical systems, so that a systematic heterogeneous total system design results. The methodology would reduce design time by 30% and raise the marketability of MEMS by 50%. The systematic methodology achieved must be validated in the field. With Bosch, Zeiss and Cadence, among others, a number of workshops have been conducted to explore how the methodology being developed for the new design system can be applied in different ways. For TETRA; IMMS staff have already developed a micro-chip for a MEMS module, integrating the knowledge it brought them into the new methodology. The ASIC involved will read and amplify the signals for forces in the nano-Newton range measured by a cantilever. This new IMMS system has been optimized to the cantilever demands. It includes not only offset compensation but also automatic error-detection. The interim results of the MEMS 2015 project were reviewed very positively in a BMBF review in October 2013.

Concluding SFB 622 colloquium. Photograph: Bettina Wegner.

IMMS and Ilmenau TU bring SFB 622 to a successful conclusion

In conjunction with Ilmenau University of Technology, the Institute was involved for 11 years on intensive research in the Special Research Project SFB 622, Nanopositioning and Nanomeasuring Machines, which came to a successful conclusion in June, 2013. The project content and results were shown on the shared Research for the Future stand at the trade fair Hannover Messe (among other places) and in lectures given at a closing colloquium. SFB 622 saw the development of the scientific and engineering basis for the design and execution of extremely precise nano-positioning and nano-measuring machines. IMMS contributed to the development of a new-type precision drive, advancing the techniques that enable the stages not only to be moved through distances accurate on the nanometre scale but to be kept steady despite the large dimensions and mass and the resulting long distances of travel. It is the intention that the Kompetenzzentrum Nanopositionier- und Nanomessmaschinen (CC NPMM), which started life in July, 2013, will apply and further develop the research results obtained in SFB 622. The cluster of SFB participants, including IMMS, will continue to collaborate on pure and applied research and in the use of the results in new applications, products and services. The collaborating group, or Kompetenzzentrum, is a structure offering the partners the possibility of future shared activity so that Ilmenau's research capacities in respect of nano-positioning and -measuring machines are established nationally and internationally. The activity will ensure that the link between science and industrial use is strongly reinforced.

As early as 10th September, 2013, less than a year into the project, the sMobiliTy consortium demonstrated a functioning prototype system. Photograph: IMMS.

HoTSens begins – a BMBF research project

Work began on the BMBF research project HoTSens on 1st June, 2013. The project partners are KS-Sensortechnik GmbH of Schorndorf, Siegert Thinfilm Technology GmbH of Hermsdorf and IMMS. The aim is to develop a system solution integrating sensors and electronics which will function reliably in industrial plant and machinery at temperatures as high as 300°C, under high pressure and in unusual climatic conditions. The collaborators are researching the enabling technology for future manufacture of sensors with the necessary capacity in such extreme situations, able to take static and dynamic measurements and to function with a standardised electronic interface. The Institute is contributing its ten years of experience in the development of high-temperature electronics. No specialised ICs have so far been available for use at operating temperatures above 225 °C. The new sensor system module which is to be constructed with high-temperature electronics for work at 300 °C will have to be able to amplify, calibrate and standardise the primary signals from a combined pressure and temperature sensor so that there is compensation for any potential error in the pressure signal. A first-time system solution will thus have been created which offers exchangeable, standardised detector modules for use under these extreme conditions. Major applications will be precise process control for plastics extrusion, also optimally efficient combustion for large diesel engines; and potential uses in the aviation industry and on-shore and off-shore drilling.

The Smart Mobility in Thüringen Project gets the green light to continue – in record time

It took only 3 days after the milestone presentation on 10 September, 2013 for all 10 companies and research institutions of the "sMobiliTy" consortium (largely situated in Thüringen) to receive the news in writing that they had succeeded in persuading the funding agencies to continue their commitment to the project. The partners have been working on an IT solution supporting electro-mobility since October 2012. They have already presented to the funders and the press a functioning prototype which demonstrates how far their development work has progressed. An example of its features is the managed charging of electro-vehicles to reflect power supply and demand on the grid as well as the user's wishes. The navigation system demonstrated will be the future means of helping extend the range of electric vehicles in dependence on current traffic conditions. As one of the ten partners in the project, IMMS is doing the R&D on a new type of sensor system to register data such as the number, type and speed of the vehicles on a "tactile" road. In addition, the Institute is establishing secure transmission of this data to the central traffic monitoring and management system and is developing a wireless environmental monitoring system.

KOMPASSION successes set KOSERNA on its course

September 30, 2013 saw the successful conclusion of the 3-year-long KOMPASSION research project, in which the German Aerospace Centre (DLR), the Ilmenau University of Technology, the RWTH Aachen and IMMS researched new designs, technology and algorithms to make the adaptive group antennas necessary for Satnav interference mitigation more compact. Antennas of this type fulfil the high requirement for interference robustness which is necessary, for instance, in safety-critical situations where unmanned aerial vehicles (UAVs) are used. They have, however, been too large and heavy to date for use in small robots or mobile devices. The receiving unit now developed is only a quarter as big as a conventional group antenna but has the same number of individual elements and serves to demonstrate the applicability of the new technology. The receiver front end circuit was developed by IMMS. It forms the link between the group antenna and the digital evaluation electronics. In addition, the Institute took part in the presentation of the paper on "Impact of Polarization Impurity on Compact Antenna Array Receiver for Satellite Naviga-

Commissioning and testing of the receiver unit developed in the KOMPASSION project, on the Ilmenau TU campus. Photograph: Björn Bieske, IMMS.

Participants in the Embedded Linux workshop organised in June, 2013 by IMMS with OSADL. Photograph: IMMS.

tion Systems" which was written in the KOMPASSION project, presented at the European Microwave Conference 2013, and nominated for the Best Paper Award. The results achieved in KOMPASSION are serving as foundation for further joint activity. In February 2014, the Ilmenau University of Technology commissioned IMMS to contribute work to KOSERNA, the successor project. KOSERNA stands for (the German for) Compact Satellite Receiver Systems for Robust Navigation Applications. As the name suggests, a more robust and accurate receiver unit is to be developed and an industrial prototype constructed. To this end, IMMS is extending the front end circuit and transferring the new designs onto a second frequency band.

Workshops and Networking Events

The workshops offered by IMMS are motivated by the desire to pass on know-how and transfer knowledge to partners in the various networks and industry. Such events also provide an environment in which new contacts can be built up and conversations held direct with Institute staff. They are an opportunity for participants to get to know the IMMS areas of expertise from seeing practical applications. The workshops and events serve also to reinforce existing relationships with industry and network partners.

AMA: An IMMS Postgraduate Seminar

February 2013 saw IMMS holding a seminar in Stuttgart entitled Embedded Systems en Route to the Smart Sensor. The scientific organiser and main tutor was Professor Hannes Töpfer. The postgraduate seminar has long been an annual event offered by the Sensor Science Association, the professional group supported by the AMA (German sensor manufacturers). It presents the fundamentals of creation, commissioning and programming of embedded systems and addresses open-source approaches, showing how these systems could be programmed and tested using existing PC infrastructures. The use of the systems in realistic scenarios and their inclusion in sensor networks by means of conventional LANs and buses are explained and various examples of practice given. This time again, the knowledge of those present was brought up to date and they were greatly stimulated. They evaluated the event as outstanding.

OSADL: Workshop on Embedded Linux at IMMS

In conjunction with the Open Source Automation Development Lab (OSADL), IMMS organised one of the workshops in the Embedded Linux series. The subject was Opportunities, Practical Approaches and Legal Aspects of Open Source, and the dates were 12 and 13 June, 2013. This was a successful continuation of the series; the participants represented many countries. The matters in the title were addressed by professionals in their fields. In a practical session, the audience was given insight into the programming of Embedded Linux with real-time capability on an embedded system. From this, the participants went on to create for themselves initial real-time applications for an industrial-standard embedded system. The practical examples and exercises, in particular, but also the lectures, were highly acclaimed by the participants. In response to popular demand, IMMS provided a further Embedded Linux Workshop describing practical approaches on 10 and 11 December, 2013.

Dr. Christoph Schäffel, Head of Mechatronics at IMMS showing the Drives Lab to VDI members. Photograph: IMMS.

At "Embedded World", IMMS was able to present the most energy-efficient board in the whole trade fair: the BASe-Box. Photograph: IMMS.

VDI Lecture Event at IMMS

At the invitation of the EKV, the working group on development design and distribution of the Ilmenau/Meiningen regional VDI group, the managers and scientists of IMMS presented to members of the VDI (the German professional association of engineers) on 7 May, 2013 the latest results of their researches into magnetic precision drives and smart energy-efficient sensor networks. The direct drive system which was presented is driven and guided entirely by magnetic force and will move a load with great accuracy on six axes. IMMS developed the engineering basics in association with PI (Physik Instrumente) of Karlsruhe and Ilmenau University of Technology. The principle is that of the maglev. It will enable industry to manufacture products of the future on a molecular scale in vacuum, as will, for example, be necessary in the production of microchips or for certain processes in materials research, surface measurement technology, the life sciences and the biotech sector. The guests were also shown energy harvesting solutions to enable wireless sensors to function autonomously in inaccessible positions or in cost-sensitive applications. These solutions are a focus of the GreenSense project, in which applications involving low-frequency movement (at below 10Hz) are envisaged, such as arises in bridge and windmill monitoring or certain automotive systems. The IMMS researchers are developing mechanical-electrical converter systems with microscopic to mesoscopic dimensions. These will effectively convert the low frequency kinetic excitation into an output power of a few microwatts.

Trade Fairs and Events

BASe-Box, the most energy-efficient board at "Embedded World"

At the Embedded World 2013 trade fair, the largest of its kind on the globe, IMMS and Bischoff Elektronik GmbH together presented their jointly-developed BASe-Box for building automation applications. This is a hardware and software platform working with extreme energy efficiency. At full load including that of the network interface, it consumes only 1.7 Watts and is laid out to cope in real time with critical use in the micro-seconds range. The BASe-box embedded system can be universally applied and is driven by Linux as optimised by IMMS. The Institute has developed comprehensive software to enable future developers to exploit the BASe-box to the full. It is suitable both to the control of KNX components and to smart metering tasks, permitting wireless retrieval of data from wM-Bus, ZigBee or EnOcean devices. The idea behind the BASe-Box is to facilitate homes tuned to individual needs, suitable to every age, frugal in energy consumption and connected online to the outside world. The "box" is at the core of an overall system applicable to every type of residence and it was developed in the Smart Home Services (SHS) network funded under the Thüringer Aufbaubank's SHS-Facility project. Connected to the Internet, the BASe-Box provides a shared communications infrastructure for all the associated sensors, actuators, and processing units which form part of home automation, locking system, fire alarms and domestic appliance monitoring. In doing so, the system meets challenges never before met en groupe by one overall system.

IMMS at the trade fairs Hannover Messe and Biotechnica

On the shared trade fair stand at Hannover entitled "Research for the Future", IMMS together with Ilmenau University of Technology presented results and project content from the special project SFB 622, Nanopositioning and Nanomeasuring Machines. As early as six months into the Smart Mobility in Thüringen project, where IMMS is one of ten partners, results were presented by the consortium on the communal stand provided by the German Federal government's electro-mobility unit, also at the Hannover trade fair. During Biotechnica, the Institute forged new contacts with biotech companies by discussing the early 3DNeuroN project results on the shared "Research for the Future" stand. The fair was also the opportunity for IMMS to make moves towards becoming a member of the "Diagnostik Berlin-Brandenburg" network. The membership began in January 2014.

Long Nights in Ilmenau, Erfurt and Jena

Three "long nights" were held on 25 May, 8 and 29 November 2013. At these celebrations of science and technology, IMMS provided many guests both young and old with many and varied insights into the R&D concerns of the Institute. In Ilmenau and Erfurt, IMMS opened up its laboratories; in Jena, the Institute was present next to the stand of its network partner, OLAB.

In all three towns, attention was focussed upon the electro-grill, on which were "barbecued" not the traditional sausages but a functioning high-temperature system with all its sensors and evaluation electronics. The exhibit revealed that the circuits developed at IMMS will also evaluate the temperatures at spots where conventional microchips cannot be used as they are so sensitive to heat. Other "hotspots" are in the vicinity of power stations turbines or vehicle engines.

The guided tours round the IMMS experimental laboratories were a sell-out. The visitors were impressed by the challenges inherent in the speed of microelectronics developments, the trend towards ever larger wafer diameters and ever tinier components. For the first time ever at a Long Night of Science, Erfurt saw the Institute accepting visitors into its experimental cleanroom. This is where IMMS carries out the characterisation and testing of ICs and investigates the reliability of electronic components and systems in accordance with international quality norms.

The drive developed by IMMS for the terahertz scanner was on show at the two "Long Nights", in Ilmenau and Erfurt. Photograph: IMMS.

There were demonstrator models from R&D projects of the Institute in both Ilmenau and Erfurt to show solutions for systems of relevance to microelectronics and mechatronics in ingenious and unconventional ways. One exhibit demonstrated the principle of security checks as people pass by a Terahertz Scanner, for which IMMS developed the drive. Another was the multimodal wireless sensor network test in which visitors could influence the temperature, the CO_2 content and the incident light beams, observing how the sensors reacted. The exhibit enabled visitors to test out modules which IMMS had developed and optimised for use in energy-efficient wireless detector networks. Another was the Light-Shooter game of skill. Guests were also shown how the finest of measurement and positioning skill is used to insert the cogs in the clockwork cogwheel of a Swiss watch. The direct drive used for the task is a high-precision positioning system completely controlled by magnetism and permitting a load to be moved accurately through six dimensions.

The attractions in Ilmenau also included an IMMS race to be run with sensor technology, the smart charging of electric vehicles, the chance to drive one, the chance to listen to music in super stereo and a lecture on "Sounds and Vibrations – seeing and altering music and voices".

In conclusion it can be said that the three Long Nights were a great success with crowds of visitors at all the exhibits, much curiosity shown and many interesting conversations held.

The IMMS team who did the Companies' Run in Erfurt. Photograph: Katrin Pleß.

The IMMS toboggan team at the BVMW Rodel Cup in Ilmenau. Photograph: Stefan Leistritz.

Life at the Institute

Thüringen Companies' Run

For the fourth year in succession, the Institute took part in the Thüringen Companies' Run. Staff members, eight in number and fleet of foot, covered the 5-kilometre zig-zag course in glorious weather through the historic centre of Erfurt on the evening of 5 June 2013, running with 5168 others from 364 companies. The two IMMS teams were cheered on not only by their colleagues along the course, but with enthusiastic shouts from the financial managing director at the starting line in Erfurt's cathedral square as they ran with zest and determination. They performed magnificently: the men's team recorded a much improved time and position, achieving the 150th place. This year was the first in which it was also possible for IMMS to field a mixed team and to be among the best 10% for individual female runners. The evening was great fun and a roaring success.

BVMW Rodel Cup

Having achieved a title the previous year in the 4th BVMW Rodel Cup, the IMMS women's team again claimed the first and second individual places this year in the 5th, once more held at the "Wolfram Fiedler" run. Two mixed teams represented IMMS at the luge race organised by the German Association for Small and Medium-Sized Businesses (BVMW), narrowly missing a place on the podium by achieving 4th and 5th.

As patron of luge, the junior world champion, Dajana Eitberger, was present to mentor each one of the more than 40 contestants from seven Thüringen companies who shot off from the special starting point for amateurs.

The weather was of the best for summer tobogganing. Fun was had in plenty and conversation went to and fro between the real professional and the greenhorn amateur, between colleagues and business partners, between competitors and spectators: all in all, IMMS had a most successful and entertaining evening.

Trade Fairs

embedded world 2013 Major embedded event for the whole value chain of embedded system technology, Nürnberg, Germany, February 2013

Hannover Messe The world's most important trade fair for industries, Hannover, Germany, April 2013

Biotechnica Europe's leading trade fair for biotechnology, life sciences and labour technic, Hannover, Germany, October 2013

Conferences and workshops with presentations and contributions by IMMS

VDI/VDE-GMM FA "MNI" Conference of the VDI/VDE-GMM committee for 4.7 Mikro-Nano-Integration, Ilmenau, Germany, February 2013

TuZ: 25th GI/GMM/ITG Workshop Testing methods and reliability of connecitons and systems, Dresden, Germany, February 2013

Analog: 13th ITG/GMM Conference "Analogschaltungen" Development with CAE-Methods, Aachen, Germany, March 2013

EuCAP 6th European Conference on Antennas and Propagation, Göteborg, Sweden, April 2013

FVEE/AMA Workshop on sensors "Renewable energy sensor systems and energy efficiency", Berlin, Germany, March 2013

DASS Workshop on circuit and system design, Dresden, Germany, April 2013

AquaConSoil 12th International UFZ-Deltares Conference on Groundwater-Soil Systems and Water Resource Management, Barcelona, Spain, April 2013

SiSax-CPS Workshop on Silicon Saxony's cyber physical systems, Dresden, Germany, May 2013

edaWorkshop Design Technology Conference, Dresden, Germany, May 2013

CDNLive! EMEA Cadence Designer Network Conference, München, Germany, May 2013

ATE Technology Day "Trends, challenges and solutions for test system automation", Radolfzell, Germany, May 2013

8th Silicon Saxony Day "Smart City", Dresden, Germany, June 2013

elmug4future Technology conference, Suhl, Germany, July 2013

9th VDI/VDE-GMM/ETG Conference for innovative compact and micro drive technology, Nürnberg, Germany, September 2013

MST Conference Microsystem technology conferece, Aachen, Germany, October 2013

18th IEEE ETFA International Conference on Emerging Technologies and Factory Automation, Cagliari, Italy, September 2013

TFG Annual Meeting of Thüringen's research groups, Ilmenau, Germany, September 2013

SoftCOM 21th International Conference on Software, Telecommunications and Computer Networks, Split-Primosten, Croatia, September 2013

DASIP Conference on Design & Architectures for Signal & Image Processing, Cagliari, Italy, October 2013

MEMUNITY Workshop Dresden, Germany, October 2013

MunEDA-Worksop User Group Meeting, München, Germany, October 2013

43rd EuMC European Microwave Conference, Nürnberg, Germany, October 2013

39th IEEE IECON Annual Conference of the IEEE Industrial Electronics Society, Vienna, Austria, November 2013

PowerMems 13th International Conference on Micro and Nanotechnology for Power Generation and Energy Conversion Applications, London, Great Britain, December 2013

IMMS

We connect IT to the real world.

STAFF AT IMMS PRESENT THEIR WORK

During the Long Nights of Science in Erfurt and Jena and the Long Night of Technology in Ilmenau, the IMMS researchers mounted vivid demonstrations to communicate their results to a wide audience. Photograph: IMMS.

3DNeuroN – 3D bi-directional interface with the brain

The microelectronic chip developed by IMMS forms part of a system which is intended to detect (and to stimulate) neuron activity in three dimensions. The image shows the probe card used in wafer-level testing of the 3DNeuroN chips. Photograph: IMMS.

Motivation

When humans have superficial wounds to arms and legs, the body is able to regenerate damaged sections of the peripheral nerves. Injuries to the head and the spinal chord, and conditions like multiple sclerosis and Parkinson's disease, however, involve damage to the central nervous system. The consequence is permanent disability, such as paralysis or blindness. There are researchers all over the world who are trying to discover whether the self-healing functions of the peripheral system also exist in the central nervous system and how they might be activated and steered. The 3DNeuroN project, funded by the EU under reference 296590, is tackling the question from one possible perspective. The Tampere University of Technology, Finland as project leader, the Swiss Federal Institute of Technology, Zürich, the Fraunhofer IDMT and Ilmenau University of Technology (TU) together with IMMS are all looking at the three-dimensional communication between neural cells, in order to gain insight for new therapies. The intention is that the 3DNeuroN project stimulate research and development in neurology and neuroprosthetics, reaching out to enterprises which are working on techniques for cochlear implants, corneal implants and DBS, deep-brain stimulation.

The IMMS researchers, together with the Institute of Biomedical Engineering and Informatics of Ilmenau TU is developing a new 3-dimensional low-power, low-noise sensor-actuator electrode system. In the future, with a method like this, it should be possible to achieve specific control of the healing of cellular tissues of the central nervous system which have been damaged by trauma or disease. The array is of a tiny (only a few mm³) stack of ten comb-like units,

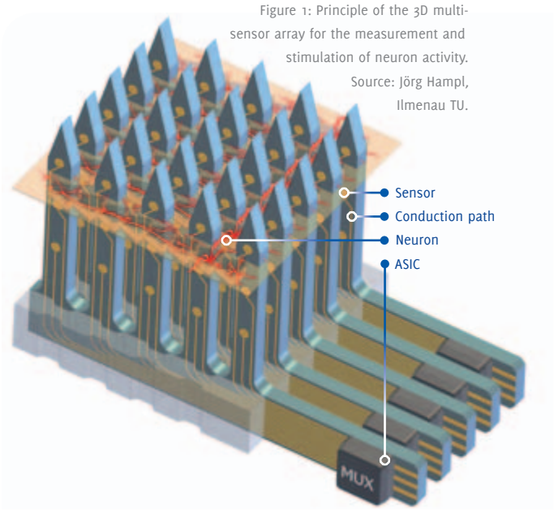


Figure 1: Principle of the 3D multi-sensor array for the measurement and stimulation of neuron activity. Source: Jörg Hampl, Ilmenau TU.

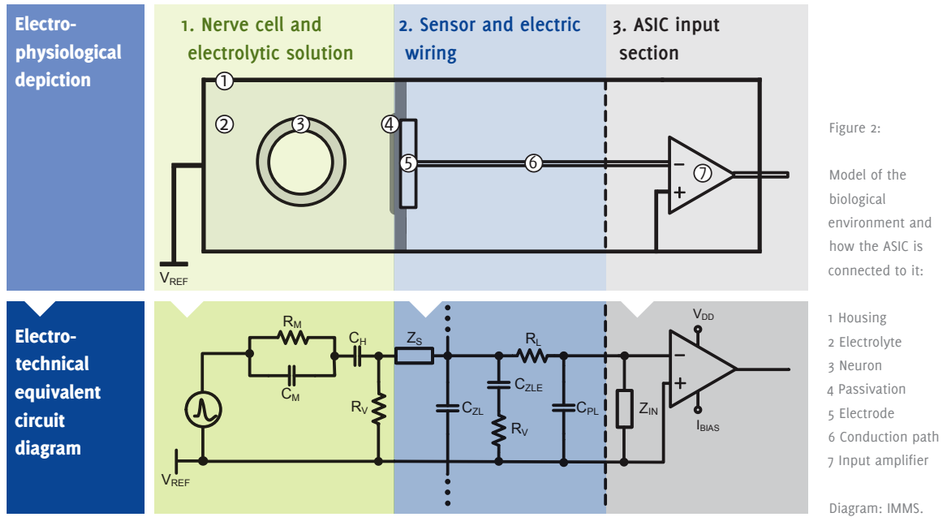


Figure 2:

Model of the biological environment and how the ASIC is connected to it:

1 Housing
2 Electrolyte
3 Neuron
4 Passivation
5 Electrode
6 Conduction path
7 Input amplifier

Diagram: IMMS.

each composed of 80 sensors (Fig. 1). 100 of the total of 800 sensors also function as actuators. Each finger in the matrix has eight sensors from which the conductor paths lead to the contact pads on the associated microelectronic chip. Each of the ten combs has its own electronics for evaluation and control purposes which has been developed by IMMS. Ilmenau TU is working on the capacitive sensor interface between the biology and the electronics and on the architecture of the comb structures.

The idea is to use the array to sense and to act as stimulus to a nerve-cell network cultivated in the lab, detecting but also affecting its spatial disposition and its electrophysiological behaviour in three dimensions. In the novel spatial configuration of the sensor matrix structure, the nerve cells will be able to grow in an almost natural environment, whereas the arrays previously available only supported planar growth. Now, for the first time, the connection between such a three-dimensional sensor format and the biological tissue is to be made capacitatively rather than galvanically, to prevent unwanted electrical currents and ensure the bio-compatibility of the array.

The IMMS Solution

The 800 sensors are arranged in a tiny space so as to enable any future implants to be kept as compact as possible. This makes it necessary for the evaluation and control electronics on each comb to be limited in size to a single chip, at most 3.8 mm wide, accommodating the conductor paths of 80 sensors. Furthermore, the chip must be able to work with almost no rise in temperature, to prevent irreversible damage to the nerve cells. Such a combination of challenges is quite new and to meet them IMMS as subcontractor to Ilmenau TU has undertaken the design and fabrication of 80-channel sensor and actuator microchips which will perform the evaluation of the signals and control of the actuators. Using 10 of these ASICs, it will be possible continuously to receive the signals from all 800 sensors at once, amplifying them at low noise. It will also be possible to stimulate the tissue using extremely low power and thus causing only a minimal rise in temperature.

Modelling

The thinking that lay behind the development of the ASICs and, indeed, the crucial element of this work, focussed on how to model the biological environment in the form of electrical signals and then on how to connect the evaluation electronics to this environment so that the biological signals might be processed. This preparatory work produced a model, an "input network". It is shown in Figure 2. The network is divided into three sections, the nerve cell and electrolyte, the sensor and its electrical wiring, and the section for the ASIC input.

The **first field** employs electrical components to describe the environment for the sensor, made up of neurons and electrolyte, and employs electrical signals to describe the interaction of the ASIC with this environment. This first section of the network enables the modelling of a variety of neuron sizes and distances between neuron and sensor and of a variety of extracellular media to form the environment. These parameters all affect the strength of the electrical signals and they can all be set to suit a particular application. For purposes of modelling, the dimensions of the neuron are converted into the mem-

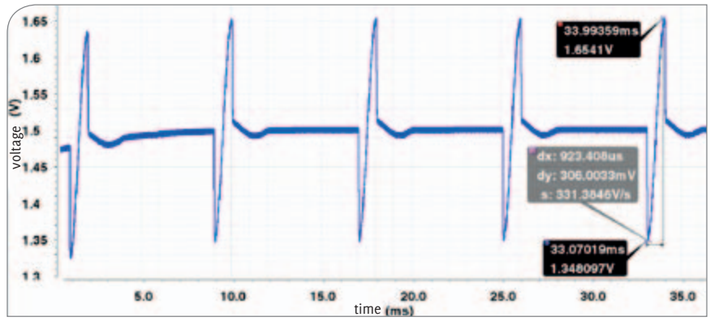


Figure 4:
This figure shows the action potential at the chip output amplified by a factor of 1,000 at a 30KHz sampling rate. The signal at approx. 300mV stands out clearly from the background noise.
Diagram: IMMS.

brane capacitance, C_M and the membrane resistance, R_M. The distance between the neuron and the sensor is represented in the model by the resistance R_V.

The **second section** of the network can be used to model various dimensions and/or materials of the sensors and conduction paths which will affect the quality of signal reception. The model system in this section was constructed in accordance with the real application to prevent potentially damaging current from the ASIC flowing into the neurons. A crucial element in the model developed is the sensor impedance Z_S. This impedance is influenced by the passivation capacitance and the electrode resistance. The passivation is used to insulate the electronic section, ensuring that it is separated from the bio-physiological environment. Additional network components were modelled for this field, such as the capacitance C_{ZL} between sensor wirings, which could not be shielded due to the architecture.

The **third section** of the model represents the connection of the ASIC to the environment by the input impedance Z_{IN}, and also includes the first amplification stage of the microchip.

Designing the ASIC

To enable the signals from the 800 sensors to be read out simultaneously and continuously, circuits were designed that were sufficient in number and adequate to the task. The main criteria to follow in the design of the ASIC were the avoidance of a rise in temperature, low power consumption and low-noise amplification. The choice of amplification needed to be appropriate to the interactions in the neural network and the interaction between the capacitatively coupled sensors and tissues, because these influence the shape and magnitude of the signals.

To meet these criteria, a low-noise amplifier (LNA) was chosen which had been reported in the literature though it was not commercially available. This capacitatively coupled, energy-efficient and low-noise LNA was used as the input circuit component. It had been developed for biological signals and was adapted by IMMS for the 3DNeuroN system, amplifying the input signal by a factor of 100. The LNA was followed by a variable gain amplifier that boosted the amplifcation factor from 100 to either 1,000 or 10,000.

Signals entering the ASIC which are almost below the noise margin, at 300 µV for instance, can thus be amplified into a usable signal (Figure 4).

The tiny (3.8 mm x 4.2 mm) ASIC has been designed by IMMS in such a way that it minimises the crosstalk or signal loss despite the high interconnection density. Furthermore, its electrical properties are resistant to mechanical stress, which may arise during the assembly or the insertion of the future implant. The pads have been laid out in different sizes and the number of pads extended so that users can send any desired test signals into the medium containing neural cell via the ASIC and use the stimulatory function.

Future prospects

IMMS has thus developed an ASIC which is adaptable to EEG signals and ECG signals and several other biosignals besides those of 3DNeuroN applications. Further work is also being considered which might, for example, lead to use of an analogue to digital converter to digitise analogue signals within the chip, or for wireless data transfer or the supply of energy by telemetry.

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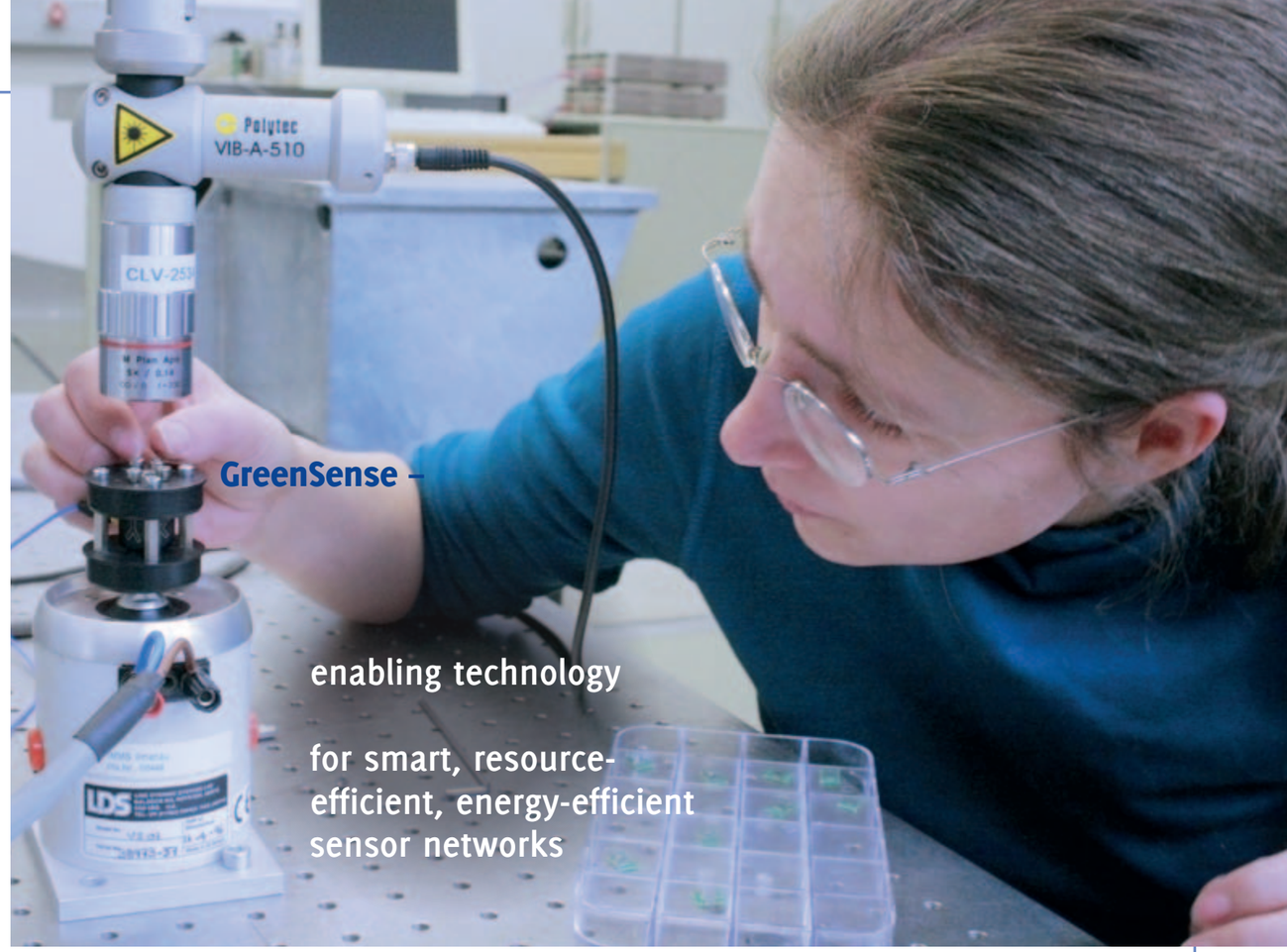


GreenSense – enabling technology for smart, resource-efficient, energy-efficient sensor networks

Setting up vibrometric analysis in the IMMS Mechatronics Lab for the energy harvesting systems developed at the Institute to be installed into the sensor networks. Photograph: IMMS.

One of the main societal challenges of the 21st century is the search for new regenerative energy sources. At the same time, the transition from fossil and nuclear power to green energy supply must be accompanied by efforts to utilize available energy and environmental resources more responsibly than in the past. Any manufacturing, transport or facility operation processes in industry as well as in the private sphere consume energy and raw materials, require capital investments and maintenance, and produce undesired emissions – frequently at a much higher level than necessary. To preserve both the environment and our current standard of living, such processes must be optimized and controlled so as to minimize resource consumption. Optimal control requires continuous monitoring of all process parameters. The finer the detail of data acquisition during the monitoring both in time and space, the better a process can be tuned to demand, resulting in fewer emissions and more efficient use of raw materials and energy. A key approach to reaching this goal is pervasive sensing, i.e. ubiquitous deployment and operation of massively distributed sensor networks.

The more sensor nodes are used in such a network, the more importance must be attached to the cost, material and spatial requirements for the hardware and the network interface of each single node. The same applies to the electrical energy required to operate a sensor. From all this follows the need to manufacture miniaturized low-power sensors at very low cost per item and to link the nodes to a network via cheap and arbitrarily scalable transmission media.

The cost per sensor node, its space requirements and power consumption can be drastically reduced if standard semiconductor manufacturing processes are used to implement both the electronic components inside a node as well as the sensors themselves. In many situations, wireless network infrastructures such as radio communication or RFID methods will be advantageous because the transmission medium

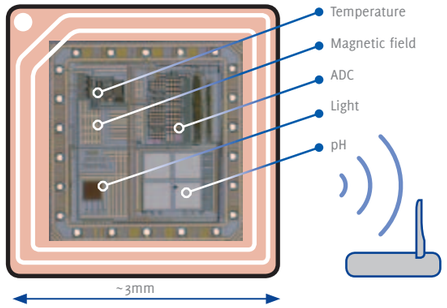


Figure 1: Research aim: Multi-parameter RFID microsensor.
Diagram: IMMS

is simply air, which incurs no installation or material costs.

The aim of the "GreenSense" research group at IMMS is to develop low-power smart-sensor components for a variety of physical quantities using only low-cost CMOS integrated circuit manufacturing processes wherever possible. The intention is that each single parameter, temperature for instance, should be measured and digitized using well below 10 µW of electrical power. Such a sensor could run continuously on a single AA battery cell with a typical capacity of 1000 mAh for more than 10 years. On the basis of these sensor components, research continues into the development of new monolithically integrated multi-sensors that are capable of recording several quantities simultaneously, digitizing them and transmitting the sensor data wirelessly by RFID communication.

Figure 1 shows the ultimate research goal: a passive, multi-parametric RFID micro sensor for future use in analysis and process automation solutions for life science and environmental monitoring applications. The sensor chip should detect physical and chemical parameters such as changes in the pH value and temperature of aqueous solutions in reaction vessels without contaminating the solution. High spatial resolution of data acquisition and scalable wireless data transmission can be achieved by arranging multiple sensor devices into a closely spaced array in the field of view of an RFID reader station.

In the context of the work on the components of the RFID sensor, IMMS has developed a new concept for a low-power digital temperature sensor, which has been implemented in a commercial 0.35 µm CMOS technology. Measurements of the temperature sensor test chip displayed in Fig. 2 showed that the desired accuracy of ±0.25 °C was achieved across the temperature range from 0 °C to 100 °C, which is the relevant range for the analysis of aqueous solutions. The power consumption of the sensor device is less than 3 µW.

Due to its low power consumption, the temperature sensor is suitable for use in energy autonomous sensor nodes that are not powered externally or by batteries but are capable of harvesting electrical energy from ambient sources. Therefore, research in the "GreenSense" project also focuses on the development of a technology for manufacturing miniaturized energy harvesting modules based on micromechanical vibration generators and integrated ultra-low power voltage converter circuits (Fig. 3). The aim is an electrostatic micro-harvester module which delivers a continuous electrical output power of at least 10 µW under low-frequency, broadband excitation in the range below 10 Hz. These conditions are typical of a number of technical applications, such as vehicle tyre pressure monitoring, in which there is currently great international demand for research on self-powered sensors.

In cooperation with the Institute for Micro- and Nanotechnology MacroNano at Ilmenau University of Technology, IMMS has developed basic structures and a wafer-level manufacturing process for micromechanical combs and springs. These components can be used to design and manufacture electrostatic out-of-plane MEMS harvester modules (Fig. 4). In this type of harvester, a central proof mass oscillates out of the wafer plane, thereby causing a periodic variation of the electrical capacitance between moving and fixed electrodes formed by the comb structures between the perimeter of the oscillator and the frame. Mechanical energy from ambient vibrations can be converted into electrical energy by electronically controlled charging and discharging of the working capacitances in synchronism with the oscillation.

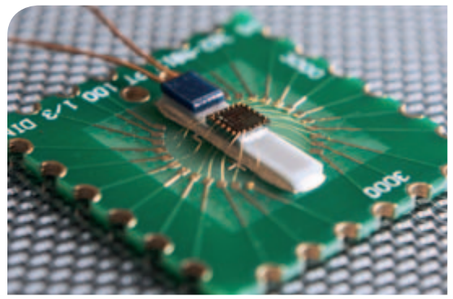
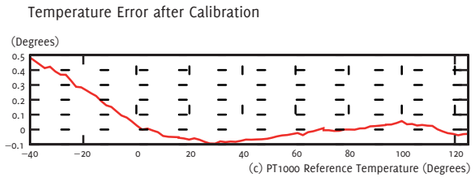


Figure 2:
Low-power CMOS temperature sensor chip with Pt1000 reference sensor (left) and measurements (below). Photograph: Jun Tan, IMMS. Diagram: IMMS.



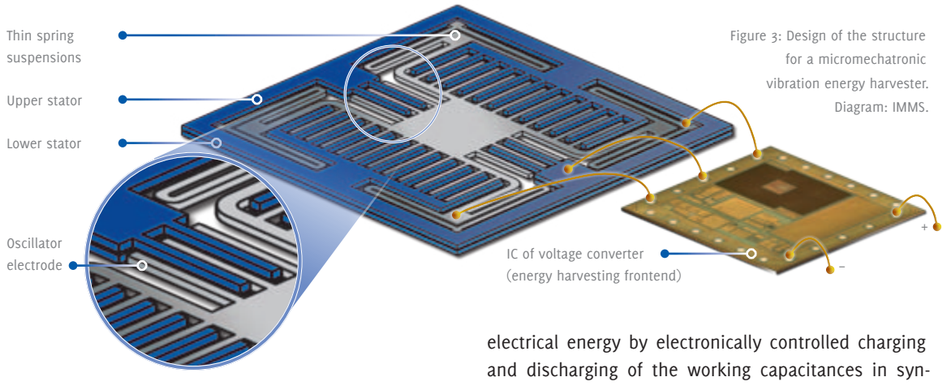


Figure 3: Design of the structure for a micromechatronic vibration energy harvester. Diagram: IMMS.

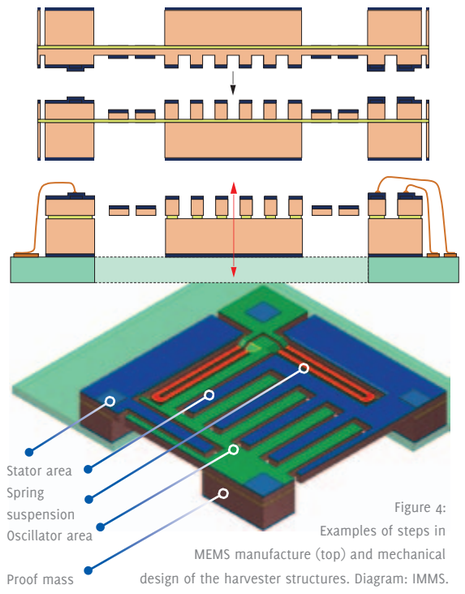


Figure 4:
Examples of steps in MEMS manufacture (top) and mechanical design of the harvester structures. Diagram: IMMS.

Fig. 5 shows microscope images of harvester test structures manufactured for experimental purposes during the application-specific MEMS process development. Several intermediate research goals have already been successfully demonstrated on these samples: the fabrication of thin yet mechanically stable spring suspensions; deep etching of comb structures up to 100 µm in height with air gap widths as small as 3 to 5 µm; and the proof that the oscillator can actually vibrate. In the final project year, the research team aims to show experimentally that the proposed micromechatronic harvester architecture is generally capable of generating a positive power output.

This project is being funded by the Thüringen Ministry of Economics, Labor and Technology (TMWAT) and the European Social Fund (ESF) under grant no. 2011 FGR 0121.

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IMMS has published in various quarters on the subject, cf. Nos. 4, 10, 12, 23, 28, 35, 39 and 40 in the 2013 list of publications, p. 51 ff.

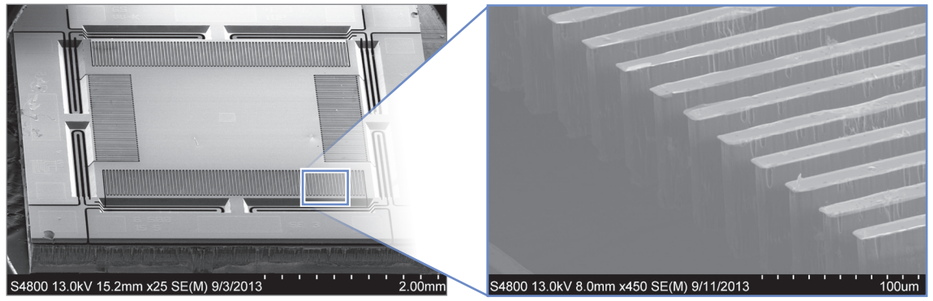


Figure 5: Microscope images of the harvester test structures.
Source: IMMS/Ilmenau TU.

EFSUES – energy-efficient airports

Partners to IMMS and Erfurt-Weimar Airport with the sensor nodes developed in the EFSUES project. They will make it possible for airport aprons to be operated more safely and efficiently in the future. Photograph: IMMS.

Issues addressed

If you are an air passenger and waiting for a plane that has been delayed, you may well be annoyed. Often you will also pay out of pocket at the individual level. At the level of a big airport, the costs associated with planes spending too long on the apron can run into the millions of euros each year. For smaller airports they will run into several hundred thousand. The many and various specialist vehicles, which an airport usually possesses only in small numbers, always have to get to the right point with the right timing, and the same is true of the staff trained to use them. For the deployment to be finely coordinated, all the sites and movement patterns for the planes, the vehicles and the staff must be known. However, if the airport vehicles are in hangars, for instance, a GPS is inadequate to their continuous location. Particularly in the case of smaller airports, ground radar systems are rarely used, being so expensive in both energy and financial terms. When visibility is low, the possibility of collisions on runways cannot usually be excluded: an airport will often have to be closed in fog, at great expense. While one or the other passenger has perhaps kept a note of his or her personal CO_2 footprint for the flight, most passengers will be unaware of the energy costs of delays or diversions. The fuel costs and energy usage, the exhaust fumes – all will be drastically increased by situations when journeys are made by specialist vehicles in vain or by mistake, when aeroplanes with their engines running have to wait before landing or before takeoff, when planes have to be diverted to other, still functioning, airports, and when passengers require alternative transport.

How to resolve the issues: a system overview

The part IMMS played in the EFSUES project was to develop a prototype monitoring system that will in future help small and medium-sized airports to manage the apron safely, with less energy consumption and at lower cost. The system will detect the presence and position of aircraft, vehicles and people with such certainty that take-off and landing can continue safely whatever the weather or visibility conditions. The special vehicles will, as a result of the development work, be operated safely and efficiently, waiting time for aircraft will be reduced to a minimum and traffic safety on the airport apron greatly improved. IMMS drew on its skills in and knowledge of wireless sensor networks for the low-energy transmitters which will serve the object- and person-location system. Honeywell of Prague made the specialist cameras which are connected to the radio signals and assist with the aircraft location. For the antenna arrays and the integration of the data into the airport software, the company responsible was SMI GmbH. Erfurt-Weimar airport provided assistance, making its infrastructure, staff and real-life testing situations available to the project.

Figure 1: Location system for airport aprons – please note that the various elements are not to scale. Photographs: IMMS.

It is a central component of the monitoring system that it should be possible to locate vehicles and people on the apron. IMMS developed sensor nodes for this purpose which include efficient energy management. Such efficiency is important because conventional location systems fail to prevent even vehicle batteries running quickly out of power. The new system equips each and every person and vehicle with the sensor node described, as an active transponder which broadcasts packets of radio signals at intervals. These go to the receiver modules, where they are recognised. Moreover, the modules identify the particular transmitter, trigger the location process and pass on the data to the upstream system. IMMS developed the receiver modules and connected their hardware and software to the SMI antenna arrays which then execute the location of the relevant transmitter by computing the angle from which the signal comes. Directional information from a number of antenna arrays enables the position of the sensor node to be detected and passed on to the upstream system for the optimisation of the process.

How IMMS developed the sensor nodes

It was necessary for the transponders to be as small and practical as possible, as they have to be carried by people as well as vehicles. They needed also to be capable of functioning over a worker's entire shift and of being simple to recharge. To meet the requirements, IMMS developed a new, particularly compact radio sensor node. The transponder being so tiny, the batteries had to be miniscule, which tended, of course, to shorten the running time for the node.

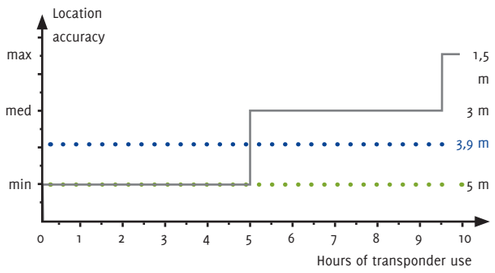
It was, therefore, crucial to the project that solutions be found for optimal energy use in the operation of the detector nodes.

The sub-components of the system, such as the sensors, the transmitter module and the measurement circuits raise energy management issues for the entire system. As they are all usually hardwired to the electricity supply, they also consume energy ceaselessly. Even though most components have a standby or energy-saving mode, there will be a permanent quiescent current. For that reason, IMMS introduced additional means of communication between the sub-systems, installing extra circuitry and status wiring. So that the charge level of the batteries could be read out at any time, a special switch provided with current limitation was constructed, which will switch the voltage measuring unit on or off. The readings and the battery characteristics allow the charge status and the consequent remaining running time to be computed. The hardware components mentioned contribute to the energy efficiency of the system layout designed by IMMS: the system itself will switch off sub-components when they are not being used. The sensor node batteries can, furthermore,

Figure 2:
Transponder being recharged.
Photograph: IMMS.

be recharged at familiar charge-points without being plugged in, thanks to design based on the Qi wireless charging standard.[1]

IMMS' development contribution was not only the infrastructure provided by this appropriate hardware, but also the software elements supporting smart energy management. Using context sensitivity, the software captures details of the environment and adapts the system to them. Most of the sensor node's energy consumption is due to radio communication, i.e. the transmission of the location data packets. The accuracy of location is influenced by the location rate, the frequency at which the data packets are sent and the speed at which a transponder-carrying person or vehicle is moving. However, there are many situations when the position of the sensor node does not need to be frequently re-determined. For instance, if a person is not moving, it is not necessary for the transponder to be constantly transmitting. And the converse is that a node which is travelling fast must send more frequent radio signals so that the accuracy is maintained. The speed of movement of the transponder (or its distance from its last signalled location) is what must be determined. To meet that need, all the sensor nodes have been fitted with an inertial measurement unit, a 3D magnetometer, an acceleration sensor and a three-axis gyroscope. The raw data from these measurements is processed first at the node itself, close to the sensor. Then the movement profile is computed in 3D and the operational mode of the sensor adapted accordingly. The energy saved by this context sensitivity can, where necessary, in critical situations, be used to improve the accuracy of location,[2] as is made clear by Figure 3. In addition, in order to make these decisions, the energy management system will incorporate information about the available energy and how long the system has been running.



In early tests, it has been shown that using this smart energy management system can improve the average location accuracy by up to 21.5% when necessary. When the new location system has undergone further tests on various airports, the intention is for SMI GmbH to run a back-to-back pilot project from 2014 on, installing the system at Lviv.

In the now concluded project, IMMS grew in know-how concerning both hardware design and energy management. The results are being put to immediate use in such research and development projects as GreenSense and SMobiliTy, where energy optimisation for platforms and the design of energy-autonomous solutions are central issues. Another benefit is that the Institute now has more to offer industry in the field.

The EFSUES project (Energieeffizienzsteigerndes Flughafenvorfeld Steuer- und Überwachungs-System, German for "airport apron monitoring and control system to improve energy efficiency") was funded by the "Land" of Thüringen and the European Union, reference TNA XI-3/2012.

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1 Barsukov, Y. Qian, J., "Battery Power Management for Portable Devices", Artech House, 2013
2 IMMS has published in various quarters on the subject, cf. Nos. 17 and 46 in the 2013 list of publications, p. 51 ff.

Figure 3: The green line shows the required minimum distance of 5 m for the average location accuracy in previous systems without energy management. The energy management system improves on that average accuracy of location by 21.5%, achieving 3.9 m (the blue line) when activity is at a minimum. Diagram: IMMS.

ANUBIS – solutions towards energy-efficient production

IMMS wireless sensor networks will capture data from existing process plant and help optimise its operation. Ideas for automation are tested in experimental plant like that shown here. Photograph: Fraunhofer IOSB-INA.

The issue

In the attempt to slow down climate change, buildings are being insulated against heat loss, automotive fuel consumption is being reduced and regenerative energy is being given every encouragement. However, the source of more than 70 % of the CO_2 emitted in Germany is manufacturing industry and the energy industry itself. It is thus necessary, above all, that energy should be saved in production processes: necessary for the protection of the environment but also, beyond that, to maintain Germany's international competitiveness through efficient manufacture. To this end, the politicians have set standards and issued directives such as ISO 50001, requiring automatic equipment to make energy savings which must be proven by detailed recording of energy consumption. The ISO 50001 standard applies equally to older plant, which tends to be rather less automated. Here the relevant data are often unavailable as they are not included in the process image of the communication infrastructure, if such an infrastructure even exists.

IMMS has, since January 2012, been jointly involved with the Fraunhofer IOSB Industrial Automation Centre (INA) in the project known as ANUBIS. This is a project funded by the German ministry supporting industry, the BMWi, bearing their reference code 16419 BG/2. the full name of ANUBIS is "Analyse und Überwachung des Energieverbrauchs in der Verfahrenstechnik und der Produktionstechnik unter Berücksichtigung betriebswirtschaftlicher Fragestellungen – Erkennung und Vermeidung suboptimaler Energiebilanzen in der Produktion". The explanation follows. The partners are working on the means not only of recording energy consumption but also improving the control of existing and future automatic equipment to enable it to be operated with greater efficiency of both energy and costs. The Fraunhofer IOSB-INA has taken on the tasks of modelling plant behaviour and of integrating the various communications systems with other components into the automated engineering processes. IMMS has designed a wireless sensor network and achieved the practical acquisition of the relevant data under the harsh conditions obtaining in industrial production. The data is then transmitted for processing. This wireless network can be added to existing plant, in particular, enabling it to capture the information required by the standard.

The solution

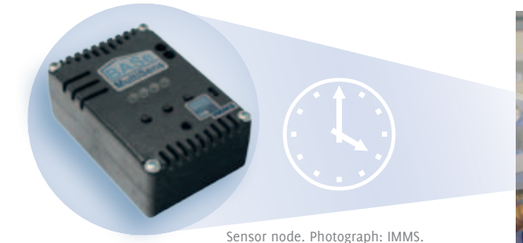
A possible way of using energy more efficiently is to replace high-energy components with more economical ones. This is a passive approach which only requires the measurement of energy consumption and identification of the components with savings potential. The active approaches followed in the ANUBIS project go further, using data on energy consumption and other aspects of the production line so that statements can be made which indicate the current status of the plant or which may serve to influence its operation. The scenarios targeted by the project partners in their development work are as follows:

- If the energy consumed by the plant or by individual components deviates from the typical consumption, an anomaly is indicated. These anomalies may, for example, be caused by wear and tear, and if identified from the energy consumption recordings may be remedied early.
- To save energy, it would be possible to switch off those parts of a system not currently required. It must be noted that to do so would involve the use of energy and of time for switching the components on and off or might put the components under greater strain. If all the interrelationships are known, the switching processes can be programmed in the most economical way.
- Given energy consumption profiles for steps in the production process, it may be possible to schedule them for the cheaper off- peak periods. In addition, with the aid of all this consumption data it will be possible to plan the stages of production so that they are more energy-efficient overall.

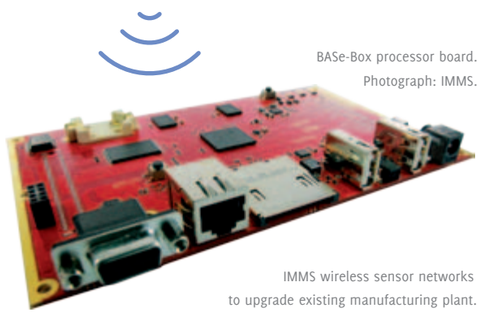
All such approaches demand a model of the plant that will predict its normal behaviour. Modelling manually is time-consuming and cannot be done without a great deal of expert knowledge. As a result, it is barely practicable. What is done instead is to create the model automatically. Here, the plant is observed during normal operation. The data acquired is then processed by an algorithm developed by Fraunhofer IOSB-INA and a model is produced. This type of approach has already been the subject of intensive research for a number of years. What is new, however, is that the model now uses the energy consumption figures for the plant and its various components or individual consumption points, such as motors, pumps or heaters. So that the plant behaviour can be modelled, and in consequence the various scenarios can be applied in practice, it will be necessary to capture the data fast enough and accurately enough. It will be particularly important to acquire all the data simultaneously. Depending on the plant and on the speed of its processes, the data capture requirements may be timed to the millisecond. Complex automated machinery will be made up of a number of very different industrial communications systems. They will be installed at different points in the plant. The challenge is thus to integrate data from a distributed, heterogeneous communications systems on a fully synchronised basis.

The IMMS contribution

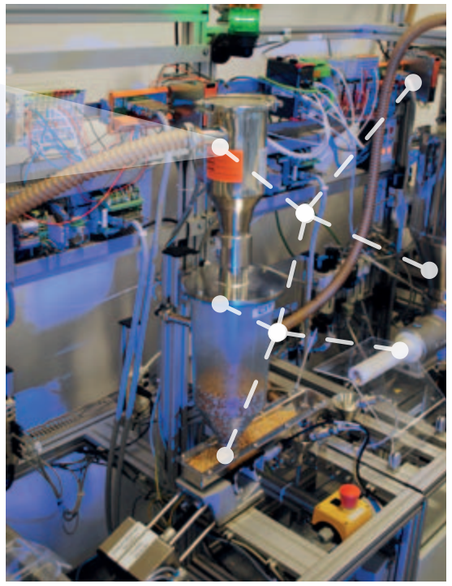
So that the automation does not have to be modified by new installations, IMMS has designed a wireless system for acquiring energy data. This enables the monitoring to take place on existing plant without endangering its current productive use. The wireless sensor developed by the Institute captures all the necessary data simultaneously and transmits it to the model generation stage. IMMS has already identified the contextual aspects and the parameters and has carried out experimental testing of the principles in practice. The sensor network is made up of several sensor modules which operate autonomously (also known as sensor nodes). They are equipped with the sensors necessary to the particular application and have a radio interface by which they communicate with each other. If there is an output from the nodes and they are operating, they will recognise other nodes in their neighbourhood and are smart enough to build their own network topology which will adapt continuously and dynamically as nodes are added to or subtracted from the sensor net. This wireless network is thus in marked contrast to the hardware usually employed in automation equipment, for it is so little trouble to install. If cables are required at all, they are laid only to the detectors and none are necessary to the data communication. No configuration of the network topology is necessary. If any other data besides energy data needs to be recorded, this can be done as long as the data is already available in analogue or digital form. As the data transfer from a number of modules by radio is non-deterministic and will thus not fulfil the above-mentioned synchronicity requirement, the time of the measurement must be assigned to it at the relevant sensor node, which means that it is the nodes which will be synchronised. To cope with the special features of



Sensor node. Photograph: IMMS.



BASe-Box processor board.
Photograph: IMMS.



IMMS wireless sensor networks to upgrade existing manufacturing plant. Photograph on right: Fraunhofer IOSB-INA.

communication by radio, IMMS has ported FTSP, the Flooding Time Synchronisation Protocol, onto the sensor network.

The wireless sensor network and the automation system are connected via the BASe-Box, an embedded Linux system likewise specially developed in house by IMMS. The BASe-Box receives the data from the sensor network and transmits it to the automation system, acting not only as gateway for the data but also undertaking the synchronisation. The items synchronised include the BASe-Box itself, further data loggers and other components of the automation system, such as servers. The synchronisation uses Ethernet and its associated protocols. The Institute has developed software that makes this common time basis available in the sensor network. The quality of the time synchronisation achieved has been confirmed by measurements. The level of accuracy achieved is to within 25 ms between the sensor nodes, which is optimal for the usual requirements of most automated processes.

Future prospects

The data-logging on a synchronised basis has already been included in certain automation bus systems and operated successfully in conjunction with the IMMS wireless sensor network. The logged data is now the basis of modelling by Fraunhofer IOSB-INA. So that the concepts and methods developed can be tested and evaluated, they are being used experimentally by the project partners in laboratory plant and on certain manufacturing lines in industry. The project is due to end in mid-2014. By then the first potential use mentioned above, the recognition of anomalies, will have been put into practice and at that time a variety of procedures which serve the purpose will be evaluated. Plant data will be logged under normal operation and during hitches in operation. This data will be compared with what the model previously derived would predict. This project is fundamental to the field of process optimisation and the foundations laid will themselves be further researched as time goes on. At the end of this project, IMMS is in a position to read out data on a synchronised basis from smart sensor nodes and to extend the know-how in addressing future issues.

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IMMS has published in various quarters on the subject, cf. Nos. 20 and 38 in the 2013 list of publications, p. 51 ff.

MEMS quality assurance

Using a vibrometer at IMMS as part of the Institute's method for identifying errors and general parameters in MEMS. Photograph: IMMS.

MEMS (micro-electromechanical systems) have boomed in recent years and are now an integral element of almost every technical device in daily life. In cars, for instance, they serve as acceleration sensors to check stability and trigger airbag release; they also monitor temperature in the air conditioner and pressure in the tyres. Because they are ever more cost-efficient in production, to ever higher quality standards, MEMS are in ever wider use.

To reduce the reject rate, whether for components or finished products, it is necessary on the one hand to define the MEMS' shape and materials parameters exactly and to adjust their manufacture accordingly – and, on the other, exactly because the applications cited above are so critical to safety, it is also necessary to monitor the quality and function of MEMS throughout the entire manufacturing process, fulfilling the requirements for ever finer tolerances and thus higher accuracy of measurement.

To meet the need, IMMS has in recent years developed a procedure which uses vibrometry for indirect identification of parameters. It has been refined and extended in a series of projects such as PRIMOS and USENEMS. It is possible to analyse MEMS vibrometrically in respect of frequencies varying from low to high. The measurement can serve on the one hand as a direct functional test, as in frequency measurement for resonators, and can be used on the other hand as the basis for the method of identifying errors and general parameters which has been developed at the Institute. An example of the latter use is determining the membrane thickness in pressure sensors and the material stress in MEMS that have thin membranes. In this type of MEMS it is also possible to monitor the effects of manufacturing processes on the stress, as is necessary when MEMS are being sawn or glued. Thanks to its many years of experience and great knowledge concerning the possibilities and limitations of vibrometry, IMMS has been able to implement a start-to-finish procedure for parameter identification, which the Institute put to use for the first time in 2013, as described below, in order to optimise the gluing processes mentioned above, thereby becoming a leader in the field.

Figure 1: Stages of parameter identification. Graph: IMMS.

Vibrometry and MEMS – the procedure as developed

MEMS structures, being measured only in micrometres, are far too delicate for tests involving mechanical contact, which would destroy them. The indirect method developed by IMMS relies on figures produced by vibrometric (and thus non-destructive) measurement of the eigenfrequencies of various test structures. FE (finite elements) simulation is at the core of the procedure and is used by the IMMS researchers to describe the functional relation between a material's eigenfrequency and the parameters requiring determination. The dimensions for shape and materials which will be of relevance to manufacture can be determined using the method in the development phase and the process parameters of finished (multiple) MEMS can be tested as early as on the wafer but not only then: also separately or in a casing (individual MEMS).

The UHF-120 ultra-high frequency laser vibrometer made by Polytec and used by IMMS to develop and validate the new method uses the Doppler effect to measure out-of-plane vibrations such as those of membrane- or beam-based MEMS structures up to a maximum frequency of 1.2 GHz. To measure the frequency response and shape of the displacement, the vibrometer laser beam scans an area of the vibrating structure defined by the user.

The stimulus given to produce vibration in active and passive structures differs. To get resonators and other active components to vibrate, high-frequency alternating current is applied. In contrast, passive elements such as pressure sensors are stimulated using an electrostatic field. An electrode linked to a voltage source (maximum 400 V) and positioned directly above the structure permits contactless stimulation of eigenfrequencies as high as 10 MHz.

It is possible with vibrometers not only to carry out functional testing but also to identify parameters. For the latter, however, various conditions must be fulfilled, which caused IMMS to develop a three-stage procedure.

In the first step it is necessary to investigate the sensitivity of the eigenfrequencies to the parameters of interest. This **sensitivity test** may take place using analytic approximation (such as is available for beam structures) or using FE simulation. The sensitivity of frequencies will depend on the parameter type and will vary according to whether the vibration is longitudinal, bending or torsional in origin. The shape and dimensions of structures will also have an effect on the sensitivity of the eigenfrequencies and thus on the usability of the procedure. For example: membranes which are thinner than 1 µm are more sensitive to stress in the material and thus suitable in general to having their properties determined by this method. However, it is also possible for membrane thicknesses in the range starting at 10 µm which is typical of pressure sensors to be easily identified with the procedure. To improve sensitivity in respect of particular parameters, special test structures other than those given can be designed and investigated.

In the **characterisation stage**, a dense grid of measuring points is used for testing whether it is possible to stimulate the vibration modes of interest. Any parameters identified are, if possible, validated. In addition, the FE model on which the identification is based can, if necessary, be adapted.

In the third stage, the vibrometer is coupled to a semi-automatic probe system so that entire wafers can be subjected to automatic testing. To keep the measurement process cost-effective, the focus in the case of the **wafer test** is on a minimal measuring time. As this time will depend on the number of measuring points, only a single point is selected for the wafer test, which means that the measuring time per die is approx. 1 sec.

MEMS parameter identification and monitoring in practice

There are many potential uses of vibrometric MEMS parameter identification. In thin layers on a scale of some 100 nm to a few micrometres, the eigenfrequencies will be strongly dependent on the stress in the material. With such sensitivity, the procedure is unique in offering non-destructive determination of material stress in thin layers. These are found typically in microphones, to take one example.

The vibrometric procedure permits stress monitoring throughout the manufacturing chain from the wafer processing to the sawing and the IC packaging

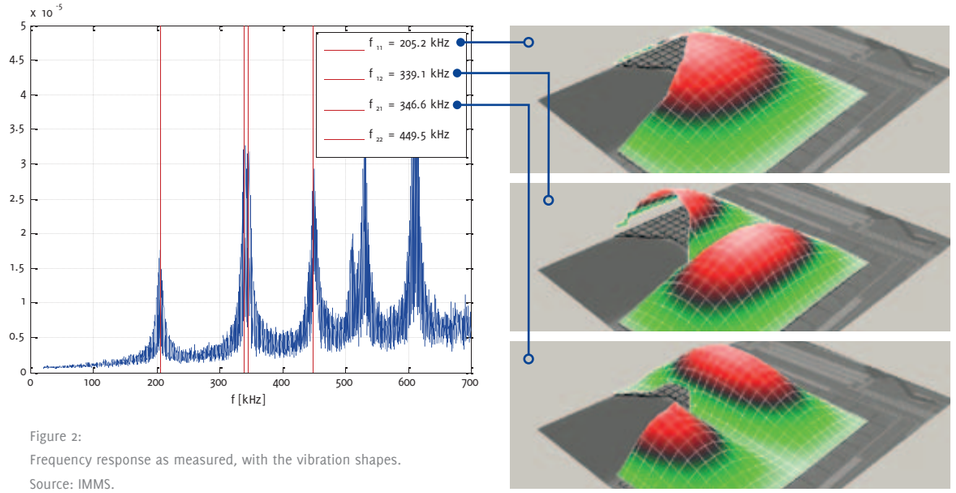

Figure 2:
Frequency response as measured, with the vibration shapes.
Source: IMMS.

processes. It also enables monitoring of manufacturing processes by evaluating eigenfrequencies and enables process optimisation on the basis of the data obtained. In the case of thin membrane-based structures, in particular, it is possible that, if the expansion coefficients have not been adjusted, gluing the sensor onto the package will generate mechanical stress. If this happens, the result will be much higher eigenfrequencies than those measured on the wafer level. Also, in the case of square or circular membranes, the procedure enables stress asymmetry such as might arise after gluing, caused by the packaging processes, to be detected. The f_{12} and f_{21} bending modes in the case of symmetrical stress will admittedly show a phase shift, but will have the same frequency value. In the case of asymmetric mechanical stress the frequencies will diverge, as is illustrated in Figure 2.

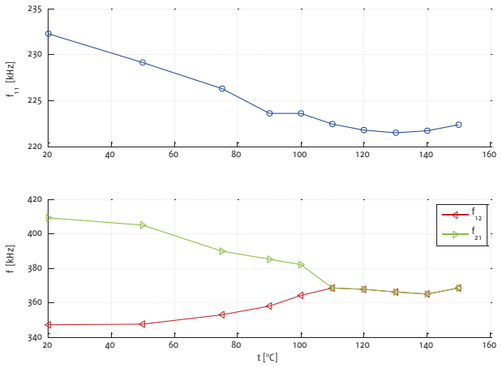

Figure 3: Measured eigenfrequencies for packaged sensors versus temperature. Diagram: IMMS.

Figure 3 gives an example of the measurements for a less than perfectly glued sensor over the temperature range 20–150 °C. The f_{12} und f_{21} bending modes are strongly separated at room temperature (values 350 kHz and 410 kHz); as the temperature rises the gap narrows, disappearing altogether at the glue's crystallisation temperature, 110 °C. The influence of the material stress caused by the glue is also revealed in the frequency response of the f_{11} bending mode. At higher temperatures, the glue becomes more elastic and the material stress expressed in the f_{11} bending mode frequency values becomes smaller.

The procedure here described allows efficient non-destructive identification of parameters for shape and material in the case of uncapped MEMS both at the development stage and in quality control during the manufacturing process. It is the intention that future research projects address how the procedure might be used for capped sensors such as acceleration sensors. It is also intended that the procedure will be used to support MEMS design in the MUSIK, MEMS2015 and GreenSense research projects, for all of which new MEMS structures and components will, in reliance on the knowledge obtained from this method of indirect parameter identification, be actively configured and verified.

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IMMS has published in various quarters on the subject, cf. No. 44 in the 2013 list of publications, p. 51 ff.

SFB 622 – on the track of the nanometre

Figure 1: Of all its knowledge, IMMS has particularly contributed in the SFB 622 its know-how on multi-coordinate drives integrated into nano-positioning systems, as for the PMS100 (illustrated). Photograph: IMMS.

To look at even the cell-phones and USB sticks of yesterday and of today is to see how fast technology has developed over recent years. In an ever smaller volume is to be found ever higher computing capacity and/or ever more memory. It is the continuous reduction in the size of the structural elements of electronic chips that makes all this possible. To take one example, the computing core of the current iPhone 5s contains components which at their smallest have dimensions of 28 nanometres. And not only here, in the field of semi-conductors, but also in other high-tech fields such as nano-electronics or materials research, the dimensions of the working parts have come down to the nanometre scale. Likewise, the disciplines of optics, opto-electronics and metrology are now making use of components with permitted tolerances of only a few nanometres for their surface characteristics or general dimensions.

For this development, the trail has been blazed and the necessary preconditions provided by the machinery and instruments in the upstream processes, without which there is no access to the world of the nanometrically possible. Which is why nanopositioning and nanomeasuring machines (NPMMs) have been the subject and goal of scientific research. With NPMMs, it is possible to position, to measure and even to manipulate a component from the macro-world with the precision and stability that is associated with the nano-world. With Ilmenau University of Technology's Department of Mechatronics among many other of the TU departments, all cooperating in the research project "Nanopositioning and Nanomeasuring Machines" (SFB 622) funded by the German Research Council (DFG), IMMS has helped to push forward nanomeasuring and nanopositioning technology to the physical and technical limits.[1]

The work of IMMS on nanopositioning systems acting over long distances of travel has contributed a vital component to the NPMMs of the next generation. The Institute's specific and ever-deepening contribution to the research is precision-drive know-how and, above all, expertise in the field of integrated multi-coordinate drives.

To move any component at all with an accuracy at sub-nanometre level is already a most delicate task. To get it to move with the same accuracy over distances of several hundred millimetres is another thing altogether. It was this that presented the particular challenge in this project, for the inevitably expanding dimensions of the drive system, the increased mass to be moved, and, most of all, the reduction in stiffness of the mechanical components all stood in the way of any in the nanometre-scale positioning. Here, integrated multi-coordinate drives offered crucial advantages over the features of conventionally structured systems relying on stacked single axes. The state of the art when the project began was track-

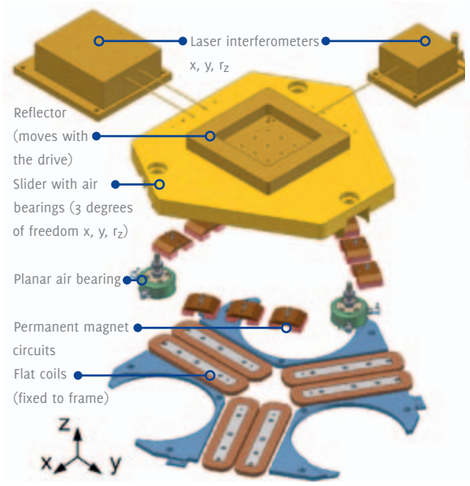

Figure 2: The basic planar drive principle, with the laser measurement system. Diagram: IMMS.

ing error down to 0.2 µm using the relevant multi-coordinate drives, accuracy primarily limited by the measuring system used. IMMS managed to develop a method which involved an air-driven planar motor, relying entirely and for the very first time on laser interferometers to measure distance and rotation. The Institute had created the conditions which would enable drive systems of this kind to be installed into a NPMM. The drive's basic principles and vital function groups are shown in Fig. 2.

Precision positioning systems are mostly operated in a closed control loop. The criterion on which the features of positioning system will be judged is the difference between the intended and actual position of the subject of measurement (known as the servo error). For this reason, research concentrated on one central question: how to lay out the individual elements of the direct drive system and combine them into a single whole system so that the servo error will be less than nanometres.

IMMS worked out methods and strategies to answer this question, prototyping one system after another and then checking and improving them by using them in experiments. An outstanding actor in this drama was the PMS100 planar motor which is

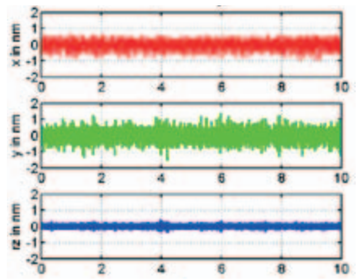

Figure 3: Position signals for x, y and ϕ_z in closed loop control, showing servo error < 0.5 nm in x und y. Diagram: IMMS.

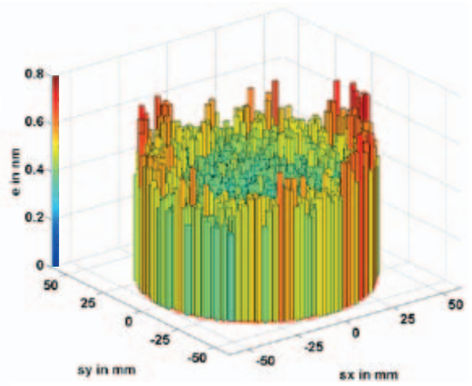

Fig 4: 2D servo error e_{xy} < 0.7 nm in the entire area of travel. Graph: IMMS.

pictured in Fig. 1. The set up demonstrates the combination into a nano-positioning system of a multi-coordinate drive (x, y, ϕ_z), an aerostatic guide and laser interferometers for the high-accuracy measurement of distance and angles. The Institute put into practice the knowledge gained, gradually and steadily improving the positioning features until the following values were achieved:

- Area of travel: Ø100 mm
- Resolution of translatory measurement (x, y): 0.02 nm
- Resolution of rotatory measurement (ϕ_z): 0.1 nrad
- Resolution of positioning in x, y: 0.5 nm
- Positioning velocity: 30 mm/s
- Acceleration: 150 mm/s²
- Mass moved: 9.6 kg

All the components of a drive system can cause disturbances and they can also be crucial in how well the system can cope with disturbances. It is thus essential to eliminate, or at least to minimise, any sources of error for a NPMM. For each prototype, the contribution of any error (internal or external) to the remaining servo error and the transmission of the errors through the mechanical drive system were analysed. By this means, a weighting was given to the error factors, and those with the greatest influence were targeted for reduction. Typical sources of potential failure include friction, vibrations, noises, temperature (of the environment or of internal components), currents of air (from the air bearing or the air conditioning), converter noise and signal quantification. At this point, it becomes clear that the aerostatic guiding of the slider is crucial to the minimisation of errors because it means that friction and the phenomena associated with it (such as stick-slip, vibrations, and alterations in forces when the direction of travel is changed) are largely avoided. However, in a system which has an aerostatic guiding, the vibration from the air bearings is a major cause of error. IMMS therefore investigated the vibrations from air bearings by means of a prototype. It was shown that

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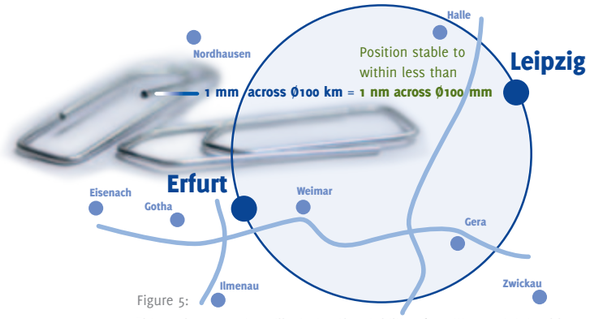

Figure 5: This scale comparison illustrates the stability of position maintained by the system: < 1 nm in an area of Ø100 mm. Photograph & diagram: IMMS.

the porous air bearing components employed cause vibration only in the sub-nanometre range.[2]

The other vital step, beside the error analysis, was the optimisation of the transmission with a view to reducing the servo error, firstly to single figures of nanometres and finally to below one nanometre. Fig. 3 shows the positioning signals for the (x, y) position and the rotation around the (z) axis ϕ_z. The servo error (root mean square deviation, RMSD) is: e_x = 0.22 nm, e_y = 0.34 nm und e_ϕ = 0.10 nm! Looking at the 2D position in the (x, y) plane, the servo error in 2D is:

$$e_{xy} = \sqrt{(e_x^2 + e_y^2)} = 0{,}40 \text{ nm}.$$

The great achievement of this drive system is that the excellent positioning stability, down to sub-nanometres, is found across the entire area of travel (Ø100 mm), as shown in Fig. 4 . Translated into macroscopic terms, the accuracy achieved is as if an object were positioned to an accuracy less than the diameter of a paper-clip in an area of land between Erfurt and Leipzig which has a diameter of 100 km (Fig. 5). That this is possible is due on the one hand to the extremely simple basic structure but even more to the investigation of the effects which are dependent on location within the system and to the fact that these are taken into consideration.

The most important positioning task (beyond reaching and maintaining the destination position) is the scanning, i.e. the exact following of a track. That a precision of nanometres, not only at rest, has been achieved is already revealed in the version shown in Fig. 6 with its tiny 0.5-nanometre steps, or the exact circular motion shown in Fig. 7. Finally, Fig. 8 is proof of the extremely small deviation from the track during the scans, at various velocities between 100 nm/s and 10 mm/s. There are two things that can be recognised: firstly, that the RMSD for the track deviation is likewise in the sub-nanometre range. Secondly, this deviation is almost unchanged even when the track velocity is higher, which represents a clear advantage over roller-guided positioning systems in particular.[3]

The eleven years of research carried out by IMMS have produced the basic drive technology for the nano-positioning and nano-measuring machines of the next generation. The research project on "Nano-positioning and Nanomeasuring Machines" (DFG SFB 622), funded by the German Research Council, was brought to a successful conclusion at Ilmenau University of Technology in June 2013. The results obtained by IMMS were used in the "NPMM200 – development and creation of a nano-positioning- and nano-measuring machine with a measured volume of 200 x 200 x 25 mm³" and in the MAG6D (magnetic 6D direct drive) among other projects. The results will also serve as the foundation of further research on the part of IMMS into nano-positioning in future years.

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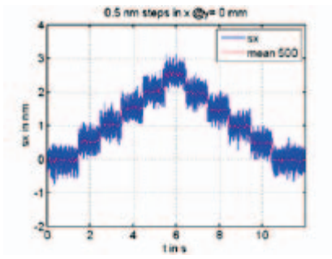


Figure 6: Steps in the x dimension, 5nm wide (blue – raw data, red – filtered). Diagram: IMMS.

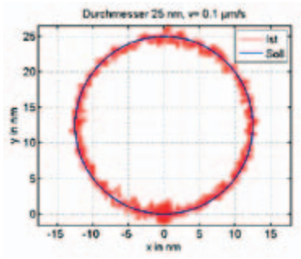


Figure 7: Circuit with diameter of 25 nm (RMSD for tracking error e_p= 0.5 nm) Diagram: IMMS.

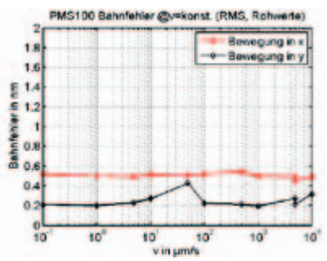


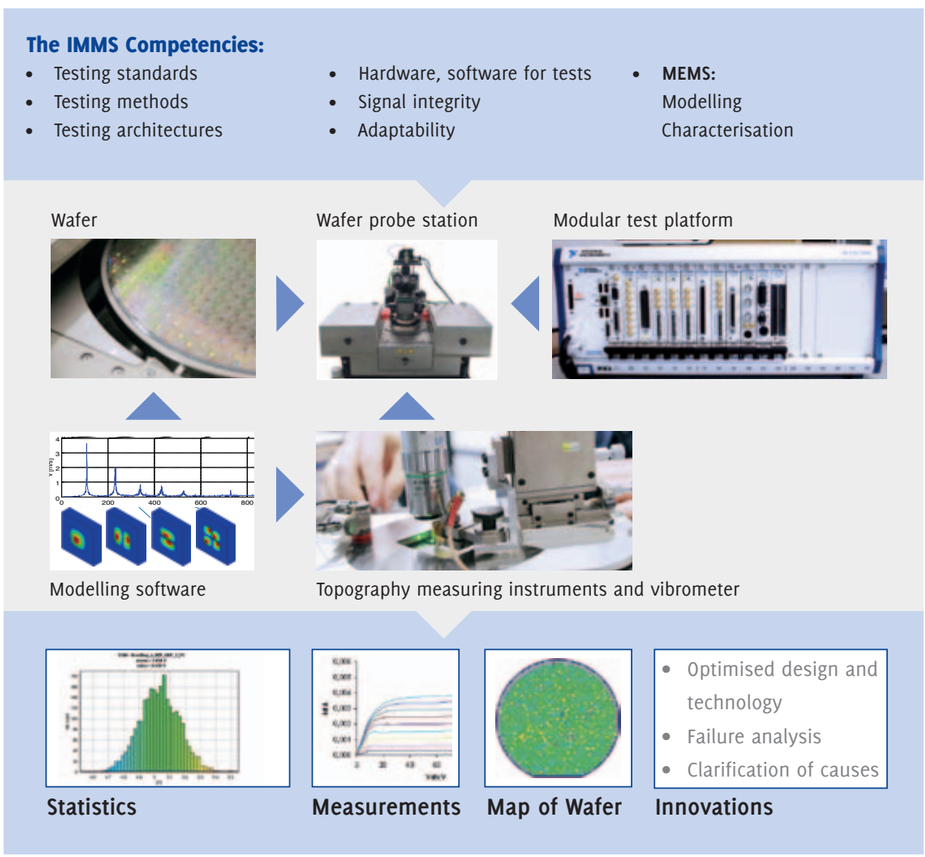
Figure 8: Tracking error during scan at variable velocity (red: movement in the x-, black: movement in the y direction) Diagram: IMMS.

Commissioning the new system in the MEMS-based micro-systems testing laboratory. Photograph: IMMS.

Micro-electrical mechanical systems (MEMS) are no more than a few micrometres in size. They unite sensors, actuators and control electronics onto a single silicon chip in a compact arrangement and are formed direct on the wafer: a method developed for MEMS production which originates in semiconductor manufacture. One use of these tiny systems is to control inkjet printer heads, another is as the microphone in a smartphone, another is as a sensor for the orientation of a gyroscope. MEMS are thus a driving force for product development. New applications are being opened up already which use established MEMS. And with new integration methods, the production volume and the turnover in this lucrative market are constantly increasing. There are also new approaches which are enabling innovative products to be developed, such as energy harvesting based on MEMS.

Having already progressed the development of MEMS in various aspects and in a number of research projects, IMMS intends to continue and build on its research in the field. The Institute was a moving force in the SMARTHIES project which finished in 2011 and was concerned with putting into practice a scalable parallel measuring system to permit the simultaneous testing of 25 MEMS structures on wafer. For many years, the Institute has been researching solutions involving ASICs and MEMS for sensor and actuator systems which will make new complex products possible. One focus is on non-destructive contactless identification of parameters to establish material properties using vibrometry. The hope is that the development of ultrasensitive integrated MEMS and/or nano-systems which go beyond silicon technologies into the realms of high-performance materials like group-III nitrides, nano-laminates or graphene. At the same time, IMMS is involved in the GreenSense research project on self-sufficient sensor systems, finding technologies for manufacture of tiny energy-harvesting modules which are based on micromechanical vibration converters. One of the aims being pursued in the current research projects MEMS2015 and MUSIK is the combination and harmonisation of the design process for the mechanical and the electronic components. The methodology is likely to reduce design time by 30 % and raise the marketability of MEMS by 50 %, and, overall, is likely to enable SMEs to compose their own individual, tailor-made solutions using a flexible MEMS and electronic toolkit system so that they can take a full part in the MEMS boom. 2014 will see IMMS proving the methodology with a prototype cantilever where the mechanical and the electronic aspects have been designed in conjunction with each other. It is also intended to design new acceleration detectors and slope sensors of extreme precision and high thermal stability which are conceived as mechanical-electronic systems. To support the concept, the Institute is developing a new MEMS design flow which will be susceptible of measurement throughout.

This has long been the background to IMMS' systematic and continuing work on MEMS measurement instrumentation. Thanks to the MEMS-T-Lab infrastructure project which received funding from the "Land" of Thüringen (project code FKZ 12031-715) and from the EU in the EFRE (regional development) context, the innovative capacities of IMMS and of its partners in research were greatly enhanced. This "T-Lab" has created the conditions for parametric modelling of MEMS and their mechanical characterisation from measurements of deformation and frequency, for without exact system-relevant parameters, the best of models is barely usable for design purposes. With the new installations, the Institute's infrastructure of modelling tools, measurement technology and laboratory equipment so that measurements can now be made to a degree of complexity not reached hitherto. The measurements are now achievable at a new level of automation and for complete wafers, which was not previously the case. The individual systems united in the new MEMS test laboratory are



Infrastructure of the MEMS test lab, comprising technology, instruments and software. Photographs, screenshots and diagram: IMMS.

- instrumentation to measure the topography of MEMS components at wafer level with an interface to a semi-automatic wafer probe station;
- a software system for the modelling of mechanical properties of MEMS systems, such as stress induced deformation and vibration, as a basis for recognition of the shape and materials parameters that are of relevance to functioning;
- a semi-automatic wafer probe station to enable the formation of rapid and accurate contact to the ICs on wafer level so that the properties can be determined in an environment shielded from light and EMI at temperatures between -50 °C and 200 °C.
- a modular test platform for electrically stimulating ICs, modules and systems and measuring their parameters; also for the exploration of flexible, high-performance test-system architectures that have efficient hardware components.

The wafer probe station and the test platform function together as a unit in three situations: during experiments on optimised technology and design, in evaluation of the quality and reliability of micro-systems; and in research into fast, new testing methods.

Since the autumn of 2013, IMMS has been combining its well-established measurement methods with the newly acquired MEMS test lab systems, starting to operate the technology and incorporate it into the Institute's IT environment. This means that from April 2014, IMMS will be testing the first wafers made in house in the context of the MEMS2015 project which is funded under reference 16M3093 by the BMBF (Federal German Ministry of Education and Research) as part of the IKT2020 scheme. Furthermore, the new infrastructure will underpin and intensify inter-disciplinary research in future projects on micro- and nano-technology right through from the drawing board to the application. It will also support increased knowledge transfer to our partners and contribute to a continuously developing research into MEMS-based microsystems for IMMS and its partners.

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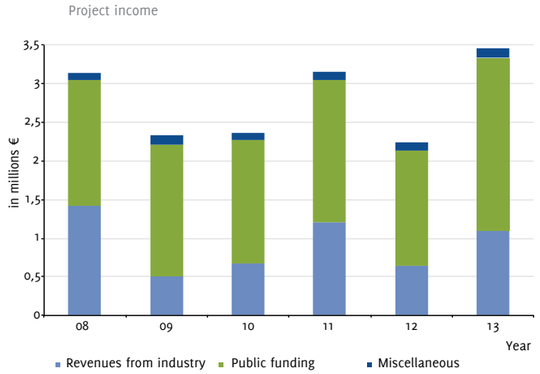
PROOF THROUGH FACTS AND FIGURES

Experimental set up for characterisation of the energy-harvesting circuit developed in the GreenSense project. The capacitor shown is serving as a larger-scale equivalent of the capacitive harvester. Photograph: IMMS.

Facts and Figures

Staff

Project income



2013 saw 87 members of staff working at IMMS. There were 56 employed as scientists and 17 (FTE) students, i. e. 84 % of the entire staff, who were directly involved in research and development.

As in all recent years, the number of students availing themselves of the opportunities at IMMS to pursue research of relevance to real life was high. 15 of them came on internships and the Institute's staff supervised nine BSc and MSc dissertations. There are five IMMS researchers currently pursuing doctoral studies at various universities.

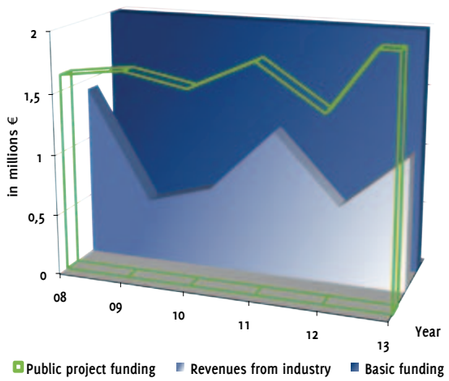
IMMS makes a point of engaging in undergraduate teaching in order to be able to attract enough of the highest quality graduates.

Income from industrial research commissions was about 71% more than that of the previous year and the income from public funding about 49% more. There has been a definite revival in the market for R&D services. One cause ist the consistent public funding of research and innovative product development; another is the fact that SMEs, in particular, have been able to increase their capital resources over the last three years.

The figures for 2013 clearly suggest that project funding will continue this positive trend. Almost all these projects are joined with other 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 will benefit SMEs most of all. The conversion process can be stabilised if the SMEs are combined into regional, product-oriented value-added supply chains. Access to innovation-driven markets is coming more and more to require systems competence in the design and manufacture of products, using micro- and nano-technologies. IMMS is excellently placed in this respect.

Thüringen as federal "Land" maintained its level of support in 2013 to keep the Institute on an even keel. The work IMMS could do in conjunction with regional SMEs benefited above all from this, but there is no longer any compensation for pay rises and inflation.

Pillars of financial support



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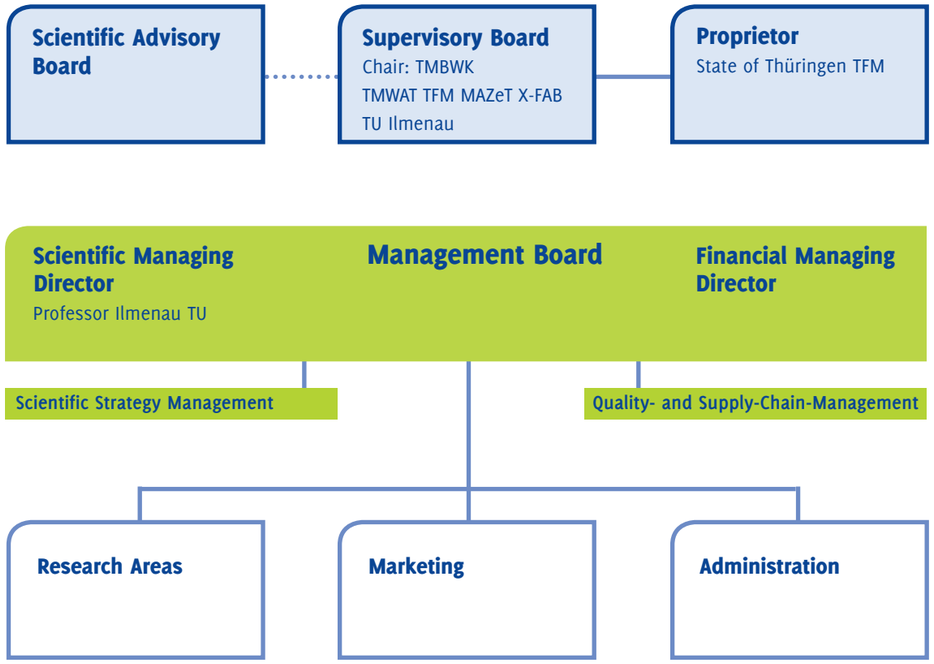
Organigram



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- System Design
- Mechatronics
- Industrial Electronics and Measurement Technology

- New Business Technologies
- Public Relations

- Scheduling/Controlling/ Documentation
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Lectures, lecture series

Prof. Dr. Ralf Sommer

„Grundlagen der Schaltungstechnik“ (“Fundamentals of Circuit Design”), lecture and tutorial, Ilmenau University of Technology, Department Electronic Circuits and Systems, bachelor students, 3rd semester

„Rechnergestützte Entwurfsmethodik (EDA) für Analog/Mixed-Signal-Schaltungen“ (“Computer Aided Design Methodology and EDA for analog / mixed-signal circuits”), lecture and tutorial, Ilmenau University of Technology, Department Electronic Circuits and Systems, bachelor students, 6th semester

Dr. Eckhard Hennig

„Modellierung und Simulation analoger Systeme“ (“Modeling and simulation of analog systems”), lecture and tutorial, Ilmenau University of Technology, Department Electronic Circuits and Systems, bachelor students, 5th semester

Eric Schäfer, M.Sc.

„Modellierung und Simulation von Delta-Sigma-ADCs“ (“Modeling and simulation of delta/sigma ADCs”), lecture and tutorial, Ilmenau University of Technology, Department Electronic Circuits and Systems, bachelor students, 5th semester

Dipl.-Ing. Sven Engelhardt

“Automatisierungssysteme” (“Automation systems”), lecture and tutorial, Berufsakademie (Thüringen's University of Co-operative Education) in Eisenach, field of study Construction, bachelor students

“Mikrocontroller-Technik” (“Microcontroller technology”), tutorials, Berufsakademie (Thüringen's University of Co-operative Education) in Eisenach, field of study Construction and Technical Management, bachelor students

Publications 2013

Papers

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2. Volker BOOS[1], Ralf POPP[2], Mirco MEINERS[3], D. MEISEL[3], A. MÜLLER[4], MEMS2015 – Schaltplan-basierter Entwurf von MEMS für Anwendungen in Optik und Robotik, in Newsletter edacentrum, 01/2013, [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ilmenau, [2]edacentrum GmbH, Hannover, [3]Robert Bosch GmbH, Stuttgart, [4]X-FAB Semiconductor Foundries AG, Erfurt.

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9. Komla Amenyo AGLA[1], Thomas ELSTE[1], Hannes TÖPFER[1,2], Modellierung und Simulation des Latenzzeit-Verhaltens eingebetteter Echtzeit-Systeme mit RT-Preempt-Patch Linux-Kernel mit SystemC, Dresdner Arbeitstagung Schaltungs- und Systementwurf (DASS), Dresden, 2013, S. 90-95, CD-ROM, ISBN 978-3-8396-0545-5, [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ilmenau, [2]Technische Universität Ilmenau, Fachgebiet Theoretische Elektrotechnik, Ilmenau.

10. Stefan HAMPL[1,2], Bianca LEISTRITZ[1], Benjamin SAFT[1], Eckhard HENNIG[1], Martin HOFFMANN[2], Ein- und mehrlagige vertikale Comb-Drive-Strukturen zur kapazitiven, niederfrequenten Energiegewinnung, Mikrosystemtechnik-Kongress 2013, Aachen, 2013, S. 524–527, ISBN 978-3-8007-3555-6, [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ilmenau, [2]Technische Universität Ilmenau, IMN MacroNano®, Fachgebiet Mikromechanische Systeme, Ilmenau.

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13. Björn BIESKE[1], Klaus HEINRICH[2], Developing and Testing RF modules in CMOS for ISM Bands using PXI platform, Transactions on Systems, Signal & Devices (TSSD), Vol. 8, No. 4, pp. 1–13, [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ilmenau, [2]X-FAB Semiconductor Foundries AG, Erfurt.

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16. Sebastian UZIEL[1], Thomas ELSTE[1], Wolfram KATTANEK[1], Danilo HOLLOSI[2], Stephan GERLACH[2], Stefan GOETZE[2], Networked Embedded Acoustic Processing System for Smart Building Applications, Conference on Design and Architectures for Signal and Image Processing (DASIP), Cagliari, Italien, 2013, pp. 349–350, ISBN 979-10-92279-01-6, online: http://www.ecsi.org/resource/dasip/2013/proceedings, [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ilmenau, [2]Fraunhofer Institute for Digital Media Technology IDMT, Project Group Hearing, Speech and Audio Technology, Oldenburg.

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19. Safwat IRTEZA[1], Eric SCHÄFER[2], Matteo SGAMMINI[3], Ralf STEPHAN[1], Matthias A. HEIN[1], Impact of Polarization Impurity on Compact Antenna Array Receiver for Satellite Navigation Systems, in 43rd European Microwave Conference (EuMC), Nuremberg, Germany, Oct. 2013, pp. 346–349, ISBN 978-2-87487-031-6, [1]RF and Microwave Laboratory, University of Technology Ilmenau, [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ilmenau, [3]German Aerospace Center (DLR), Institute for Communication and Navigation.

20. Björn KROLL[1], Sebastian SCHRIEGEL[1], Stefan SCHRAMM[2], Oliver NIGGEMANN[1], A Software Architecture for the Analysis of Energy- and Process-Data, in proceedings 18th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA), Cagliari, Italy, Sept. 2013, pp. 1–4, ISBN 978-1-4799-0864-6, Digital Object Identifier: 10.1109/ETFA.2013.6648146, IEEE Catalog Number: CFP13ETF-ART, [1]Fraunhofer IOSB-INA, Application Center for Industrial Automation, Lemgo, Germany, [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ilmenau, Germany.

Presentations and posters

21. Björn BIESKE[1], Alexander SCHULZ[2], Einfluss der Messumgebung auf die Performance des HF-Tests, 25. GI/GMM/ITG-Workshop: Testmethoden und Zuverlässigkeit von Schaltungen und Systemen (TuZ), Dresden, 24.02.2013–26.02.2013, [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ilmenau, [2]Technische Universität Ilmenau, Fakultät für Elektrotechnik und Informationstechnik, Ilmenau, Vortrag.

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23. Jun TAN[1], Marco REINHARD[1], Dirk NUERNBERGK[2], Eckhard HENNIG[1], A Digitally Trimmable Wide Temperature Range 0.35-µm CMOS On-Chip Precision Voltage Reference, 13. ITG/GMM-Fachtagung: Entwicklung von Analogschaltungen mit CAE-Methoden (Analog 2013), Aachen, 04.03.2013–06.03.2013, [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Germany, Ilmenau, [2]FH Jena, Fachbereich Elektrotechnik und Informationstechnik, Germany, Jena, Vortrag.

24. Björn BIESKE[1], Klaus HEINRICH[2], Evaluierung von HF-CMOS-Modulen für Kommunikationssysteme mit flexibel konfigurierbaren Testsystemen (PXI), 13. ITG/GMM-Fachtagung: Entwicklung von Analogschaltungen mit CAE-Methoden (Analog 2013), Aachen, 04.03.2013–06.03.2013, [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ilmenau, [2]X-FAB Semiconductor Foundries AG, Erfurt, Poster.

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27. Komla Amenyo AGLA[1], Thomas ELSTE[1], Hannes TÖPFER[1,2], Modellierung und Simulation des Latenzzeit-Verhaltens eingebetteter Echtzeit-Systeme mit RT-Preempt-Patch Linux-Kernel mit SystemC, Dresdner Arbeitstagung Schaltungs- und Systementwurf (DASS), Dresden, 25.04.2013–26.04.2013, [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ilmenau, [2]Technische Universität Ilmenau, Fachgebiet Theoretische Elektrotechnik, Ilmenau, Vortrag.

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