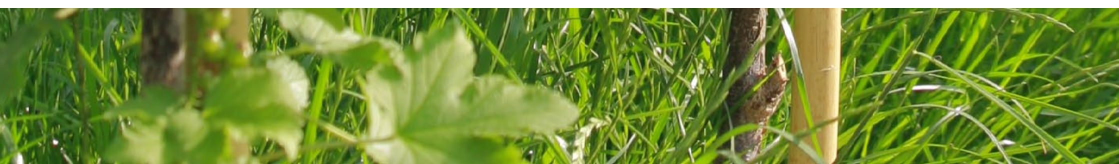
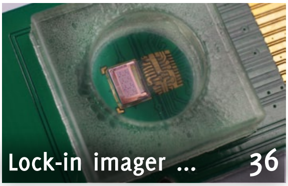
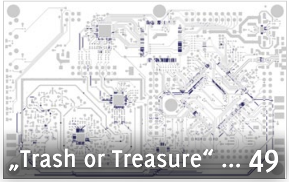
IMMS

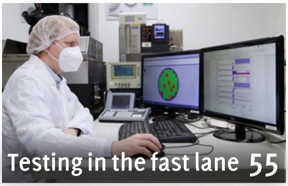
ANNUAL REPORT

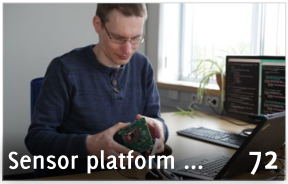
2020

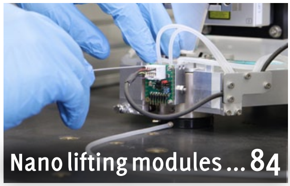












Contents

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

Frontispiece: Smart distributed sensor technology of IMMS for monitoring microclimate and drought stress for studies of the Horticulture Teaching and Research Centre in Erfurt. Photo: IMMS.

Dipl.-Kfm. Martin Eberhardt and Prof. Dr. Ralf Sommer in one of the laboratories where integrated sensor systems are characterised and tested at IMMS. Photograph: IMMS.

Dear readers,

Also for us at IMMS, the year 2020 brought new challenges. Despite home office and strict Corona rules, we managed to work on all projects largely as planned in order to launch internationally successful innovations with our partners and thus strengthen their competitiveness, especially during this time. We also served the small and medium-sized enterprises in the region with our involvement in the Cross-Cluster Initiative Thüringen. There, together with 19 Thuringian branch networks and clusters, we offered all the necessary company-specific Corona information centrally via a platform in order to support SMEs' ability to work.

We also used 2020 to further sharpen our strategy. On this basis, we were able to acquire important research projects in 2020 for the expansion of know-how, with which we will further advance application developments and strengthen the region. This report outlines milestones already achieved:

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In the research field of **integrated sensor systems**, we have developed a novel lock-in imager chip for time-resolved fluorescence imaging and integrated it into a sample application for quantitative readout of strip tests. The chip enables applications in in-vitro diagnostics for which concentrations need to be detected quickly.

For highly complex and safe integrated sensor systems, we are also researching to automate their design and testing with AI algorithms and machine learning. The results achieved in 2020 by the IntelligEnt research group include automated modelling in chip design, intelligent layout processing and accelerated measurement data analysis.

In the research field **smart distributed measurement and test systems** we completed the development of a networked scalable ultrasound and volume flow sensor platform for optimising energy efficiency with industry partners in 2020. The system is currently being prepared for market launch in 2022.

In the research field of **magnetic 6D direct drives with nanometre precision**, we have been working in the DFG Research Training Group NanoFab since 2017 on solutions for a highly dynamic drive system for multi-axis processing of objects with nanometre precision. In 2020, work on nanometre-precise lifting modules was significantly advanced.

We would like to thank our employees for all these and other solutions, for their expert knowledge, their personal skills and for the constructive and trusting cooperation. They are the ones who create competitive advantages for partners, promote young talent and are involved in associations, clusters and committees.

We would also like to thank the German "Land" of Thüringen for its institutional funding and our committees for their impulses and suggestions on our strategy to bring Thüringen forward as a transfer institution. We thank all research partners for the inspiration for our research and development, which we have been able to translate into application-oriented solutions for industry.

We sincerely thank all our R&D partners, sponsors and friends who encourage us and want to shape the future with us. We thank them for their trust, their commitment – and their application ideas.

Find out in this report what has become of some of these ideas. We would like to develop further ideas with you and we look forward to working with you. Enjoy and benefit from reading this report.

Univ.-Prof. Dr.-Ing. Ralf Sommer
Scientific Managing Director

Dipl.-Kfm. Martin Eberhardt
Financial Managing Director

› *Integrated sensor systems*
› *Distributed measurement + test systems*
› *Mag6D nm direct drives*
› *Contents*
* *Funding*

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

Vision, mission, values and **strategic foci**

Vision

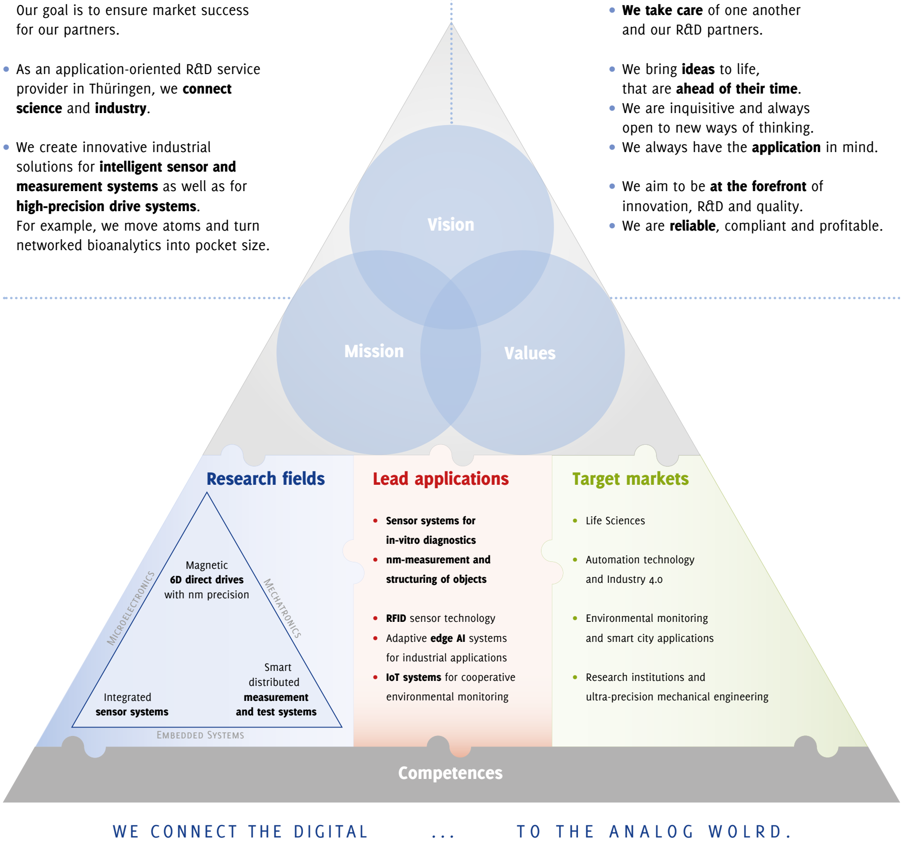
We are **innovative researchers** from **Thüringen** who turn **science** into **applications**. As a leading research partner, we transform ideas into products.

Mission

- **We advance our region.**
  Our goal is to ensure market success for our partners.
- As an application-oriented R&D service provider in Thüringen, we **connect science** and **industry**.
- We create innovative industrial solutions for **intelligent sensor and measurement systems** as well as for **high-precision drive systems**.
  For example, we move atoms and turn networked bioanalytics into pocket size.

Values

- We are a **team on an equal footing**.
- **We take care** of one another and our R&D partners.
- We bring **ideas** to life, that are **ahead of their time**.
- We are inquisitive and always open to new ways of thinking.
- We always have the **application** in mind.
- We aim to be **at the forefront** of innovation, R&D and quality.
- We are **reliable**, compliant and profitable.



As a research institute that has evolved over many years, we at IMMS have built up a wide range of experience in manifold projects and topics. On this basis, we have re-adjusted our target markets and sharpened our research fields. The connecting link is our lead applications, which thus form the bridge between research and application or market: We conduct research to harness cutting-edge results from science for industry. Through application-oriented developments we strengthen industry's competitiveness with innovations. Developments with industry in turn reveal the need and challenges for novel approaches, which we address in our research fields.

Research fields

We have bundled our research activities in the three research fields of **integrated sensor systems**, **smart distributed measurement and test systems** and **magnetic 6D-direct drives with nanometre precision**. Further core subjects are grouped under each of these. The topics are interconnected and interdisciplinary, which is also reflected in the cooperation with research partners such as Ilmenau TU as well as with regional and national research institutions, technology providers and industry.

Core subjects

In our core subjects, we research specific focal points within a research field. In the research field "Integrated sensor systems", we investigate miniaturised systems manufactured in semiconductor technology consisting of microelectronic and/or microelectromechanical components for sensors applications. In the core subject **CMOS-based biosensors**, we are researching CMOS-integrated transducers and their interaction with biological receptors. For such and other highly complex integrated systems, we are researching **AI-based design and test automation** as another core subject to make the design and testing of these systems significantly more efficient and safer. In the research field "smart distributed measurement and test systems", for example, we are deepening the core subject of **distributed IoT systems** in order to create energy- and resource-optimised embedded systems, e.g. for the "Internet of Things" or self-sufficient sensor networks for environmental monitoring and smart city applications.

Lead applications – the bridge between research fields and target markets

Based on our research, we are developing **sensor systems for in-vitro diagnostics**, for example, which enable individual, decentralised health monitoring for everyone with electronic rapid tests. We are researching energy-efficient solutions for **RFID sensor technology** and for **IoT systems** to open up new applications for cooperative environmental monitoring and to make processes in industry more resource-efficient. We are researching solutions for **adaptive edge AI systems** to enable AI on low-consumption embedded systems in industry and to network them in real time. To be capable of manufacturing the ever-increasing complexity of these integrated systems on ever-smaller semiconductor surfaces, we are researching ever more precise drives for **nanometre measurement and structuring of objects**.

Working hand in hand with the Technische Universität Ilmenau

Being an affiliated institute of Ilmenau University of Technology (TU), IMMS benefits from networking with the university while the TU benefits from the Institute's close relations with industry. In 2020, IMMS again worked on scientific projects and issues with numerous departments in the fields of electrical engineering and information technology, mechanical engineering, computer science and automation as well as mathematics. In parallel, IMMS is strongly networked with industry. To develop internationally successful innovations for health, the environment and industry, IMMS is integrated into regional and national innovation networks as well as industrial clusters. The use and bundling of technological competences and the development of joint market strategies provide valuable practical impetus for the research activities of the Institute and the Ilmenau TU.

Selection of joint projects

IntelligEnt*: Reseach group on AI and Machine Learning for the design and verification of complex systems

In the "IntelligEnt" research group, IMMS and the Data-intensive Systems and Visualization Group (dAI.SY) at Ilmenau TU have developed application-oriented concepts for machine learning in microelectronics design and linked them to existing methods and tools. The aim was to use the immense potential of machine learning for further technical and scientific developments into assistance systems for chip designers and thus to achieve significant cost and risk reductions in the design of integrated analogue/mixed-signal systems. Results are presented in this report in the integrated sensor systems chapter.

More on IntelligEnt at www.imms.de.

Go to this chapter.

MagSens* research group: MEMS sensors for detecting the weakest magnetic fields

The MagSens research group, led by Ilmenau TU, has investigated magneto-electrical MEMS as sensors for measuring the weakest magnetic fields for applications in e.g. medicine. Conventional ultrasensitive magnetic field sensors require elaborate cooling to at least –196 °C. The sensor principle researched in MagSens is based on magnetostrictive-piezoelectric multilayer systems and will enable these measurements without cooling. IMMS contributed to the finite element modelling and simulation of the sensor principle, among other things.

More on MagSens at www.imms.de.

The NanoFab* RTG: high-speed fabrication with nanometre precision

Until 2022, 13 doctoral students, including one at IMMS, are working on solutions for tip- and laser-based 3D nanofabrication in extended macroscopic workspaces in the NanoFab Research Training Group 2182 funded by the DFG. They are supervised by professors and scientific staff of Ilmenau TU and IMMS under the direction of the Institute for Process Measurement and Sensor Technology of the Faculty of Mechanical Engineering. IMMS is developing solutions for a drive system that will enable multi-axis highly dynamic machining of objects with nanometre precision.

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

The IMMS contribution is, as "Migration Model Factory“, to put its shoulder to the introduction of Industry 4.0 technology for the improvement of plant and processes. An example of what this means is retrofitting machinery and equipment with wireless and networked sensors so that data can be obtained and processed which will underpin new diagnostic, maintenance and service concepts. Combining open-source software with universal electronics platforms for components that are compatible to Industry 4.0 is a powerful means of achieving real-time-capable innovation fast and affordably.

Growth Core HIPS* – High-Performance Sensor Systems for Harsh Environments

In the HIPS growth core, IMMS and Ilmenau TU, as well as 5 other research institutions and 12 industrial companies from Thüringen, are working until 2022 to build a technology platform around the SiCer technology researched by Ilmenau TU and Fraunhofer IKTS. It combines silicon technology (Si) with ceramic multilayer technology (Cer) and enables novel, robust, highly integrated SiCer high-performance sensors for liquid and gas sensor technology. IMMS is working on novel functional structures of sensory and actuator micromechanical elements and developing miniaturised evaluation circuits for the SiCer sensors.

Joint encouragement of young academics

IMMS not only complements teaching at Ilmenau TU with extensive practical offers. Some courses are also given by IMMS staff. In addition, Prof. Sommer and Prof. Töpfer are involved with courses in basic education and in the Master's programme. IMMS promotes the motivation and training of students through its practical and industry-related offers, among other things, through numerous topics for internships.

› *Integrated sensor systems*
› *Distributed measurement + test systems*
› *Mag6D nm direct drives*
› Contents
* Funding

More on NanoFab at www.imms.de.

More on SME 4.0 at www.imms.de.

More on HIPS at www.imms.de.

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

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

In 2020, 29 students were supervised at IMMS during their internships or theses or worked here as student assistants. Furthermore, there are 8 IMMS researchers currently pursuing doctoral studies at various universities. The fact that we have so high a proportion of students from Ilmenau TU is an indication that our intensive efforts in fundamental education are in the habit of bearing fruit. We think this is why highly motivated, high-flying students find their way to IMMS, to our great delight. School pupils, too, are given insight into the work of IMMS by means of events and internships or by having their coursework supervised.

Long-term practical training for challenging research subjects

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

Research subjects for students at www.imms.de.

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

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

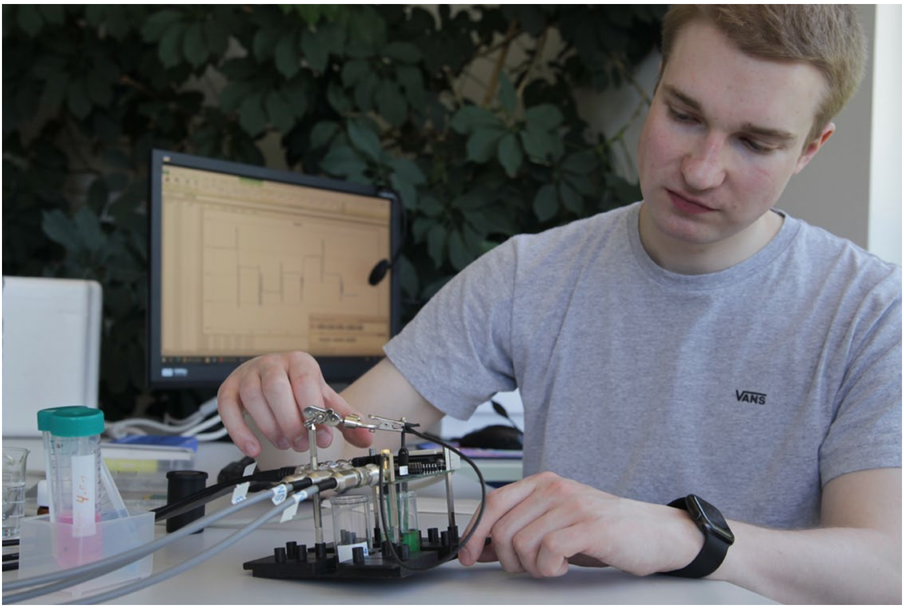
Florian Kögler, analogue IC design engineer at IMMS

"I have been at IMMS since 2017, since 2020 as a researcher in the microelectronics department. I started here with a technical internship and my bachelor thesis, which involved the modeling of fluorescence-based optical measurement systems. In my studies of electrical engineering & information technology at Ilmenau TU I specialised in circuit design. During my time at IMMS I discovered new challenges that went beyond the contents of my studies. For example, I combined the topic of my Bachelor's thesis with the scientific fields of opto-physics, chemistry and electrical engineering.

I like the fact that many topics for student work are integrated into ongoing projects and their results are incorporated there. At the same time, sufficient time and support is provided for the students' scientific work. This and also the pleasant collegial environment persuaded me to do my Master's thesis at IMMS.

Research subjects for students at www.imms.de.

It involved the development of ion-sensitive field-effect transistors (ISFETs), which are capable of measuring the pH value of liquids, among other applications. The



Florian Kögler with a test set-up for the development of ion-sensitive field-effect transistors (ISFETs) for applications in in-vitro diagnostics. Photograph: IMMS.

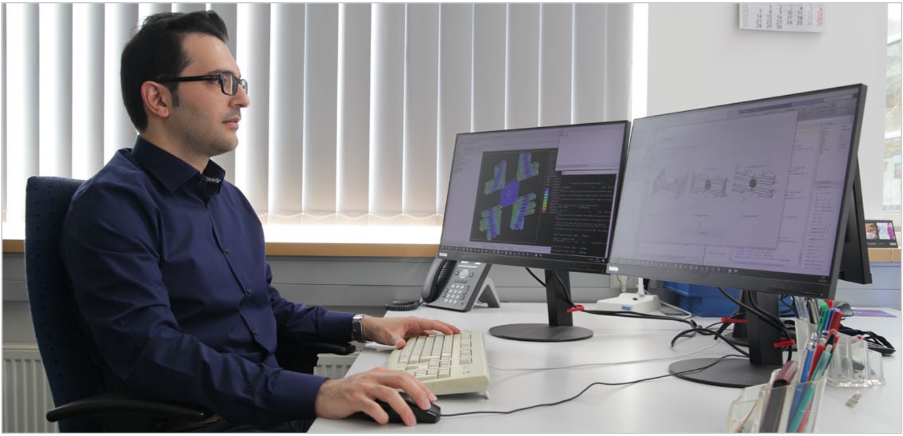
ISFETs were to be implemented in a standard CMOS process to enable cost-effective production without costly additional processes as well as integration into sensor systems. In this approach, a variety of problems can arise that complicate their use compared to conventional pH glass electrodes. In advance, our internal research group on integrated system solutions for life sciences applications therefore conducted a broad research to identify and evaluate the problems and to find possible solutions. In my master's thesis, I then dealt with the various steps of the semiconductor design process, starting with the requirements definition, through circuit design, to the layout, which requires special attention for ISFETs. This resulted in a test structure with different transistor elements and surfaces from which the best one could be selected.

The topic of ISFET sensors still accompanies me even after my studies. Together with a team from the fields of microelectronics and measurement technology, we succeeded in setting up the test structure and running it successfully. In characterising them, interesting insights keep coming to light, but also new questions and hurdles to overcome. Based on the initial results of the test structure, a sensor chip with a digital interface was also developed in the SenpH project. In addition, I am investigating the implementation of machine learning approaches within the VE-ARiS project in order to make product piracy of circuits more difficult.

I find the working atmosphere at IMMS very pleasant. The work in the research projects offers the opportunity to contribute and pursue one's own ideas. I like the institute-wide exchange of knowledge across departments, which takes place both in the regular institute colloquia and through discussions during the lunch break. I look forward to continuing to encounter exciting topics at IMMS.“

Projects on integrated sensor systems: www.imms.de.

Voices of colleagues at www.imms.de



Alireza Nikpourian simulating MEMS structures in ANSYS for the design of novel multisensor applications. Photograph: IMMS.

Alireza Nikpourian, PhD, MEMS development engineer at IMMS

"My first acquaintance with the microelectromechanical systems (MEMS) dates back to 2013 when I started my career as a PhD student in Iran. Back then, I was offered to do a PhD dissertation on the numerical modelling of the nonlinear dynamics of a MEMS resonator. As I started my research in this field, I was really fascinated by the functionality of these tiny systems, their extraordinary applications, and how practical they are in our daily life. After five years of doctoral research and one year of working in the R&D department of an industrial company, I decided to expand my experience by working in an international environment. Then, I decided to move to Germany to fulfill the goal I had set for myself. As I was looking for a job, I came across an attractive job vacancy in the IMMS website. I applied for it and after a while, I was invited for an interview. Luckily, everything went well and I ended up getting the job and being employed as a scientific research assistant in the MEMS group, which is part of the "Mechatronics" department. As I started my career in IMMS, I joined the MagSens project, which was in cooperation with Ilmenau University of Technology. In this project, we conducted research on a multilayer microbeam resonator consisting of a piezoelectric and a magnetostrictive layer, which can be used as a small magnetic field sensor. When the piezoelectrically actuated beam is exposed to a magnetic field, the magnetostrictive layer shows a change in its Young's modulus, the so-called delta-E effect, which in turn causes a change in the eigenfrequency of the whole structure. The resulting frequency shift gives rise to the measurement of the magnetic field. Beside research projects, we are also in

Services for MEMS at www.imms.de.

MagSens at www.imms.de.

close connection with industrial partners and X-FAB MEMS foundry. Thanks to our in-house developed MEMS library, we also design sensitive MEMS accelerometers for our international customers.

By providing access to the industrial software products and modern laboratory equipment, IMMS provides the infrastructure for working on leading edge multi-disciplinary research topics, and bringing ideas into practice.

It is my pleasure to work in such an active and dynamic research institute. People here are passionate about their job and most importantly, they are ready to support each other. Whenever a problem occurs in the course of a project, no matter how big the problem is, always someone is there to help and give hints to solve it and push the project forward. Working with inspired and talented colleagues on challenging projects helps me develop my skills and mutually contribute to further development of IMMS."

Markus Ismer, scientific staff member at IMMS

"During my bachelor studies 'Electrical Engineering and Information Technology' at Ilmenau TU I was able to get to know different laboratories of the university institutes through the internships. I really liked the possibility to visit an affiliated institute of

Voices of colleagues at www.imms.de

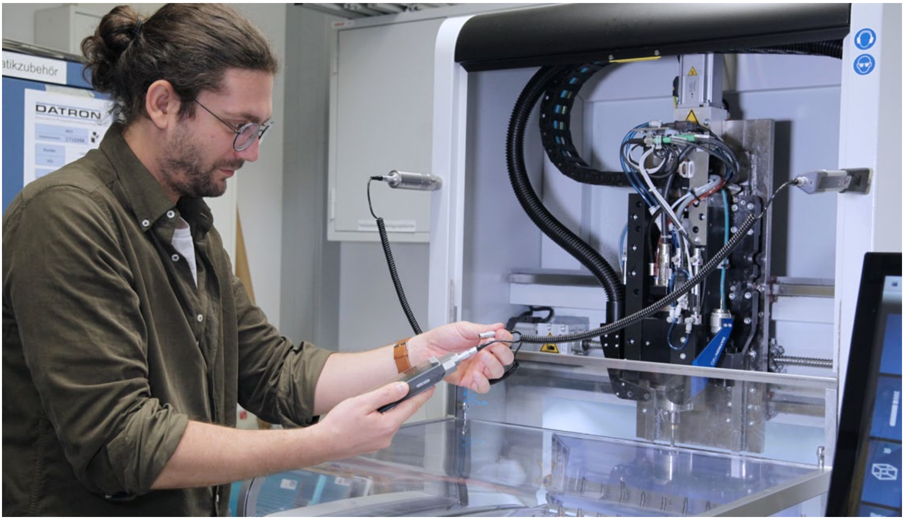
Markus Ismer with his demonstrator for the energy-autonomous read-out of LFA test strips via NFC. Photograph: IMMS.

the Ilmenau TU, namely IMMS, through Prof. Sommer. And one semester later I took the opportunity to visit the Erfurt branch office of IMMS as well. This invitation came from Prof. Sommer and Eric Schäfer and also allowed me to tour the production and laboratories of the IMMS industrial partners X-FAB and Melexis. Through this Student Day 2018, which was dedicated to microelectronics, I was able to gain many interesting insights and listen to exciting technical presentations. I gained the impression that there is a very pleasant atmosphere especially at IMMS and decided to work there as a student assistant during my studies. I was not mistaken about the pleasant working environment and helped in the 'Industrial Electronics and Measurement' division of Michael Meister with the construction of a high-temperature transistor test system.

In doing so, I particularly appreciated the good professional care. The decision to do my technical internship in the seventh semester at IMMS was therefore not difficult for me. This enabled me to apply my theoretical knowledge to practical problems. And in my subsequent bachelor's thesis, I developed a demonstrator for energy self-sufficient read-out of an LFA test strip using NFC. I was able to extensively exploit my creativity and productive technical discussions with my later colleagues as well as good technical equipment, such as an extra RFID measuring station, helped me to successfully complete my thesis. I was very happy about the opportunity to work part-time as a research assistant at IMMS alongside my following master's studies. Due to the proximity to the university and especially the flexible working hours, it is possible for me to gain extensive, application-oriented experience and to further develop my skills alongside my studies. Currently I am working in the BMBF KI-EDA project on a modular mixed-signal test system for ASICs. Since I really like the work at IMMS and the collegial environment, I will also write my upcoming Master's thesis here. The topic will follow on from my previous work at IMMS."

Services for characterisation and test at www.imms.de.

More on KI-EDA at www.imms.de.



Umut Onus with an ultrasonic testing device that is to be scaled up as an edge AI system for multi-channel signal processing and data transmission in real time. Photograph: IMMS.

Umut Onus, embedded software engineer at IMMS

"Ever since I was involved with electrical engineering, I have had a keen interest in signal processing and telecommunications. During my bachelor thesis, I have worked on a testbed for antenna arrays using microcontrollers. That was my motivation to take a step into higher education at Ilmenau TU for the Master of Science program on Communications and Signal Processing.

My master thesis was on the topic of automated radio-signal characterisation for low-altitude drone-to-mobile radio channels using artificial intelligence (AI) assisted methods.

Such a topic drew my interest due to the use of drones and widely used mobile phones in rescue operations after disaster scenarios. Throughout the time, I built interest in AI and its application in the signal processing field. With the advances in machine learning and artificial intelligence approaches, we can automise labour-intensive tasks using mathematical models which will greatly impact future industrial technology. During my Master's degree at Ilmenau TU, I took the great chance to work as a student assistant on a signal processing project with the IMMS System Design team, and I could get to know more about the embedded system perspective of electrical engineering. A great opportunity to research merging signal processing and AI on embedded systems was presented to me by IMMS.

I am now working as a research associate in the field of signal processing and AI for its optimal deployment on resource-constraint embedded devices. My target is AI-assisted optimal machine health status prognostics in Industry 4.0 domain applications, such as machine tool health condition estimation and remaining lifetime predictions. My research interests include machine signal representation in unique and compressed ways in time/frequency/space domains, ranking, and selection of built signal features for their optimality on target embedded platforms. To this end, the required AI-processing chain (from signal acquisition to model deployment) is investigated and build optimal solutions for industrial processes at hand.

With the know-how at IMMS, not only I can build AI models that can help shape the future of maintenance and prognostics, but also I can contribute to the optimality and availability of such models for embedded devices. With such optimal embedded solutions, we can diagnose machinery conditions with affordable embedded platforms on reduced carbon footprints.

Thanks to colleagues that are highly competent in their fields, working towards my goals at IMMS is very convenient. Professional communication is uncomplicated and clear. Despite having a long lockdown and a home office period, it is still comfortable to work with other colleagues through integrated digital platforms. I could not stress enough my appreciation for everyone that contributed to this healthy working environment."

More on the KIQ project at www.imms.de

Voices of colleagues at www.imms.de

Voices from industry

Dalibor Stojkovic, Senior Director of Engineering, Accessory and Wearable Solutions, BU AOS, ams OSRAM group, Managing Director ams Sensors Germany GmbH, Jena. Photograph: private source.

Dalibor Stojkovic, ams OSRAM

"What motivates us at ams OSRAM is our drive to explore and design new technology. Bringing intelligence to light and passion to innovation, we enrich people's lives. With our vision to become the uncontested leader in optical solutions, we will continuously advance our technologies in biosensing, spectral sensing, health monitoring and visualisation. We imagine radical new applications that make life better for everyone – from making journeys safer, medical diagnosis more effective to daily moments a richer experience. Because Sensing is Life.

Our colleagues from IMMS are exactly the right partners for this. In various research and development projects, we work closely with IMMS in the areas of IC and sensor development to further expand our competitive edge in the market. IMMS supports us in particular in the design and verification of integrated circuits (ICs) as well as in their characterisation and the development of special test setups.

We appreciate both the technical expertise of IMMS and the high level of their commitment to our joint projects. The proactive and agile way of working of the IMMS colleagues is an essential building block for our joint success. We are extremely satisfied with IMMS and would like to express our sincere thanks for the very good cooperation."

www.ams-osram.com

ams OSRAM

Christian Paintz, Melexis

Christian Paintz, IP Portfolio Development Manager, Melexis GmbH. Photograph: Melexis.

"At our site in Erfurt, we develop and produce highly integrated circuits mainly for the automotive industry, including for example the driver for ambient light LEDs, motor controller but also sensors.

In the process, our chips are constantly faced with the challenge of being safe and robust while integrating more and more functions at the same time. On the basis of this, it is necessary to comprehensively analyse and test the circuits. This generates considerable amounts of data that have to be evaluated in detail. On the other hand, due to the smaller silicon structures and the higher integration density associated with them, for example unwanted interference caused by crosstalk between neighbouring cells in the layout becomes more critical and must be identified and reduced to a tolerable level.

The IntelligEnt research group, of which I was privileged to be the speaker, addresses this by using machine learning methods early in the design and characterisation process. This approach promises to integrate empirical knowledge into new methods and thus make our chips better through elegant structures and procedures.

More on IntelligEnt in this report.

Particularly in the evaluation of measurement data, IMMS has impressively demonstrated that a learning algorithm is on a par with manual evaluation – while saving a great deal of time. We are also continuing to pursue methods for circuit and layout analysis, as we see great research and application potential here as well. In the near future, methods for automatically mapping the power consumption of our chips will also help us to increase energy efficiency."

Melexis
INSPIRED ENGINEERING

www.melexis.com

Hans-Christian Fritsch, Ilmsens

“Ilmsens GmbH was founded in 2016 as a spin-off from Technische Universität Ilmenau and develops state-of-the-art ultra-wideband sensors to the highest quality standards. Our sensors are internationally applied in liquid analysis and in short-range sensor technology to detect compositions of complex substance mixtures as well as the smallest movements. We develop and manufacture our ultra-wideband sensors, antennas and application-specific measuring systems in Ilmenau.

Hans-Christian Fritsch, Managing Director, Ilmsens GmbH, Ilmenau. Photograph: Christoph Gorke.

IMMS is an important regional R&D partner for us, helping us to further miniaturise our technology and make it more cost-efficient. With IMMS, we have transferred an important component of our high-performance sensors from an FPGA to a dedicated ASIC. In addition to the methodological support, we also benefited from the possibility to use IP blocks already developed by IMMS, which allowed us to accelerate the development process even further. The IMMS’ competencies in integrating hardware simulation and hardware testing with signal processing algorithms also helped us to optimise the overall system even before chip production.

Ilmsens has strong regional ties and commitment. We were therefore particularly pleased that we, as a start-up from Thüringen with IMMS as its research institute, were able to create an innovative high-tech solution with the Thuringian semiconductor manufacturer X-FAB. We appreciate the high level of expertise and flexibility as well as the customer-oriented and target-oriented way of working of the colleagues from IMMS. We would like to take this opportunity to express our sincere thanks for the very successful collaboration and look forward to further cooperation.”

www.ilmsens.com

„With our engineering designs, we have specialised in compressed air, the most expensive energy source. We offer our customers an all-round service for the energy-efficient use of compressed air in industry. This ranges from efficiency consulting to customised product developments of measurement and sensor technology to professional support. In this way, we are already enabling operating cost reductions of up to 60% in compressed air production. However, up to 30% of the expensively provided compressed air still escapes through leaks in the lines.

Peter Otto, Postberg+Co. GmbH. Photograph: Postberg+Co. GmbH.

We are continuously working on developing new solutions. Through cooperation with SONOTEC, the idea arose to combine their mobile systems for leakage detection, which they developed with IMMS, with our measurement technology. Our systems are stationarily installed in large supply facilities with widely branched pipe systems and measure the consumption and flow of compressed air, nitrogen, oxygen, helium and CO_2. We have combined our know-how and jointly developed a holistic monitoring system for compressed air systems. It consists of wirelessly networked and permanently installed ultrasonic sensors from SONOTEC and our volume flow sensors, which can be used to monitor and evaluate the energy efficiency of compressed air systems.

IMMS has developed the modular embedded sensor platform for this purpose. This high-performance and scalable system takes over the digital processing of the sensor data for each measuring point of the monitoring system. So that sensors can be flexibly adapted for different purposes without having to make changes to the hardware, IMMS has developed the signal processing components using a model-based design technology and configured the application algorithms for integration into the electronic components. The platform is also equipped for future requirements and can be integrated into maintenance systems, as appropriate communications interfaces and protocols were implemented by IMMS.

We are very satisfied with the result – the many years of IMMS experience in the design of embedded systems, with industrial projects and also the system understanding of IMMS from the previous product developments with SONOTEC have clearly contributed to the success. In addition, the uncomplicated and at the same time professional way of working as well as the pleasant and objective communication have helped us to make good progress. We plan to use the developed system for our measurement technology and service offerings and look forward to the next opportunity to cooperate with IMMS for new developments.“

POSTBERG + Co.

www.postberg.com

„STABL Energy has developed a technology that fundamentally improves battery storage systems. These storage systems can be used in many ways, e.g. for solar power, for an interruption-free power supply in hospitals or to avoid peak loads in production. With our modular inverters, the construction of electricity storage systems is considerably simplified. Instead of statically connecting a central inverter to battery modules, as in conventional systems, our STABL modules are dynamically interconnected with their integrated inverters. Compared to conventional systems, losses are reduced by up to 70 % and thus operating costs as well as CO_2 emissions are reduced by up to 40 % per year. To achieve this, the modules must communicate with each other in a highly synchronised manner. At the same time, we are constantly working on improving our technology. New software solutions for the real-time communications of the modules are always necessary for extended functions.

Arthur Singer, Gründer und CEO STABL Energy GmbH. Foto: Viktor Schwenk.

For this purpose, we have been working with IMMS since 2018. It has supported us in evaluating possible software architectures and has developed various software modules for the central STABL controller as well as for the controllers of the modules. Among other things, IMMS has implemented the Modbus interface for the central controller, i.e. ported the stack of the communications protocol to the master node and connected it to our software. With this communications interface, systems can be integrated into higher-level structures. This makes it possible to integrate our technology into energy management systems, for example.

IMMS is also a flexible partner for us beyond R&D projects in order to develop high-quality solutions quickly and efficiently. The self-image at the institute of thinking our way into our systems and proactively delivering solutions has helped us a lot. We are very satisfied with the results, as well as with the targeted, constructive and collegial way of working. We have come to know and appreciate IMMS as a very competent partner with easy and fast communication and almost even faster implementation of our requirements. We can highly recommend IMMS and look forward to further cooperation.“

STABL

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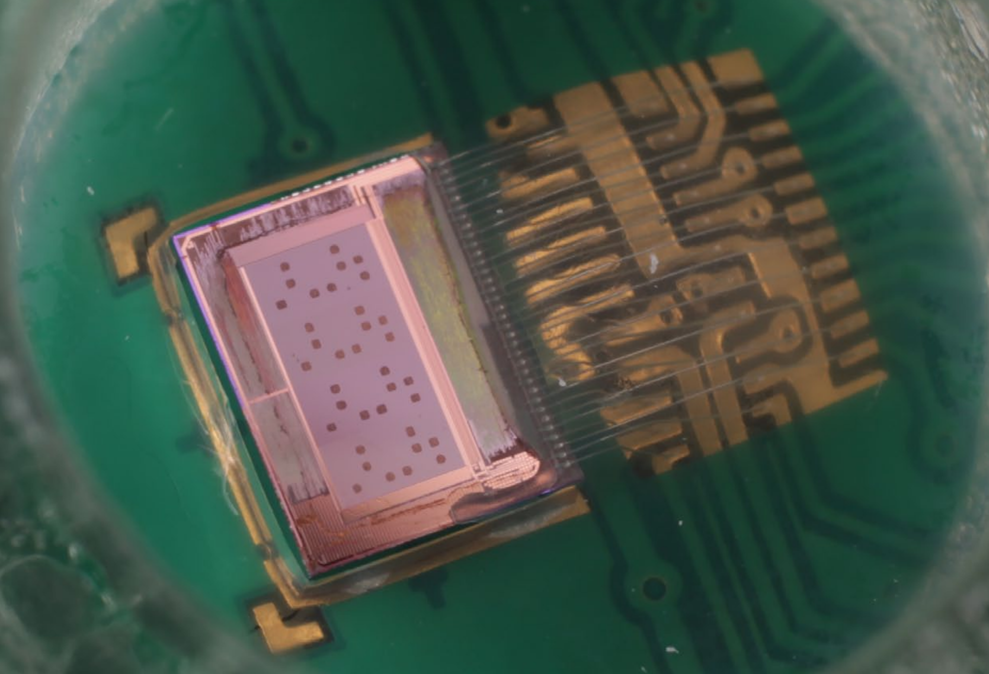
RESEARCH FIELD

INTEGRATED SENSOR SYSTEMS



IMMS has developed this lock-in imager chip for time-resolved fluorescence imaging with europium. The image sensor can be mounted on an application-specific cartridge that is plugged into the demonstrator. In the MEDIKIT project, two types were developed for this purpose - a cartridge with a lens for reading out strip tests and the fluidic cartridge shown here with a cavity and biocompatible encapsulated sensor chip for molecular biological detections directly on the chip surface. Photograph: IMMS.

EFRE
EUROPE FOR THURINGIA
EUROPEAN REGIONAL DEVELOPMENT FUND

EUROPEAN UNION

The project on which these results are based is supported by the German "Land" of Thüringen and co-financed by European Union funds within the framework of the European Regional Development Fund (ERDF) under the reference 2017 FE 9044.

Research field: **Integrated sensor systems**

› *Integrated sensor systems*
› *Distributed measurement + test systems*
› *Mag6D nm direct drives*
› *Contents*
* *Funding*

In the research field "Integrated sensor systems", we investigate miniaturised systems manufactured in semiconductor technology consisting of microelectronic and/or microelectromechanical components for sensors applications, as well as methods to design these highly complex systems efficiently and safely.

Integrated sensor systems connect the analog with the digital world:

Electrical, mechanical and optical parameters can be directly detected, amplified, digitised and transmitted on these silicon chips with an edge length of just a few millimetres. They are mobile, energy-efficient, precise and powerful and therefore represent the key technology for the Internet-of-Things (IoT). Functionalised chip surfaces can be used to measure additional physical as well as chemical and biological parameters. With integrated sensor systems, structural sizes in the µm range can be achieved and thus properties can also be detected on a molecular scale, such as in the sequencing of DNA.

Projects on integrated sensor systems: www.imms.de.

Goal: new applications through functional integration and miniaturisation

We aim to pioneer new applications through functional integration and miniaturisation. In the field of CMOS-based biosensors, we are researching CMOS-integrated transducers and their interaction with biological receptors. In the area of ULP sensor systems, we are reducing the energy demand of integrated sensor systems through intelligent power management and ultra-low power (ULP) circuit technology. In the field of MEMS sensors, we focus on piezoelectrically excitated cantilever or bar-based microelectromechanical sensors (MEMS), e.g. to detect the weakest magnetic fields for medical applications. Our intensive research into AI-based design and test automation enables our partners and us to automate the development of highly complex integrated sensor systems and make them safer.

Research with commercial technology for industrial exploitation

The goal of our research is always industrial exploitation. We therefore focus on system design with commercial semiconductor technology. Large quantities can be used here to achieve competitive and cost-effective solutions. In addition, IP protection and trustworthiness are strengthened.

Integrated sensor systems are incorporated into solutions for all target markets of IMMS. In the lead applications of sensor systems for in-vitro diagnostics and RFID sensors, we focus on the use of integrated sensor systems in life sciences as well as in automation technology and Industry 4.0 target markets.

Highlights of 2020 in our research on integrated sensor systems

Start of the Ovutinin* project: CMOS imager for time-resolved fluorescence measurement on test strips

For an innovative rapid test for fertility diagnostics, IMMS is developing an image sensor for time-resolved fluorescence measurement.

In Germany almost every tenth couple between 25 and 59 years suffers from an unfulfilled wish to have children. Ovulation tests, among other things, are one way to help. These are used in a similar way to pregnancy tests and usually detect the ovulation-inducing luteinising hormone (LH) in urine, which significantly rises in concentration one day before ovulation. Some tests also detect oestrogen, which increases three or four days before ovulation. The hormones are made visible with antibodies on the test strip.

Current digital rapid tests with interchangeable test strips use these two hormones to detect ovulation about four days before. The test is only reliable if it is used with morning urine.

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag
ZIM Zentrales Innovationsprogramm Mittelstand

IMMS is developing an image sensor for time-resolved fluorescence measurement for a new type of rapid ovulation test. Photograph: Serhii Kuch, Pixabay.

In the Ovutinin project, a new rapid test for fertility diagnostics is being developed which can be used at home with test strips and with a reader to identify the fertile phase up to six days before ovulation, regardless of the time of day the test is taken.

Test strip by Senova will combine immunological and chemical detection for the first time

The lateral flow test is being developed by our partner Senova. It will not only provide a simultaneous determination of oestrogen and LH values, as is currently customary, but also progesterone and creatinine values in urine using immunological and chemical detection methods. Progesterone is used to prove that ovulation has actually occurred. The creatinine content enables a normalisation to the amount of urine and thus measurements to be taken independently of the time of day.

Current readers limit the number of test lines

Current readers for home application are mostly based on reflectometric measurements. Therefore, they reach their limits if more than two hormones are present on a stripe test. The reason for this is that the demands on positioning accuracy increase with the number of test lines. The lines on the test strip must first be manufactured accurately and the strips must then be precisely aligned in the reader.

Image sensor chip of IMMS for time-resolved fluorescence measurement for more precise readings

IMMS is developing the prototype for a compact and cost-effective digital reader that will evaluate the test strips by transillumination. The core of the device will be a CMOS imager chip for time-resolved fluorescence measurement. This sensor IC will be designed for the new test strip in terms of its geometrical and optical properties. Inaccuracies in positioning can then be easily compensated by software.

In the test strip, the fluorophores which are available after a reaction with biomarkers are optically excited and emit photons which are detected by the chip. In time-resolved fluorescence measurement, this emission is measured after the excitation light has disappeared. As a result, no further optical filters are necessary. Thus, even very weak fluorescence light can be quantitatively detected and higher sensitivities can be achieved.

Ovutinin at www.imms.de.

IMMS and iba are developing an integrated circuit for miniaturised, fast and broadband impedance analyses. Photograph: IMMS.

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag
Forschungsnetzwerk Mittelstand

BICCell* project launch: Impedance chip for various new applications

The Institute for Bioprocess and Analytical Measurement Techniques e.V. (iba), Heilbad Heiligenstadt, and IMMS presented details of the 30-month BICCell project, which started on 1 July and in which an energy-efficient broadband impedance chip for real-time cell culture monitoring and test strip measurement is being researched and developed, to the project committee of nine companies at the iba premises on 2 October 2020.

Impedance spectroscopy must become smaller and cheaper

Impedance spectroscopy itself is already established in scientific laboratories, where it is used, for example, to characterise batteries and fuel cells, to monitor the kinetics of chemical reactions and as a measurement method for biosensors. “Measuring impedances is not only interesting for us as a manufacturer of microbioreactors. It can be a promising competitive advantage for a wide range of applications and open up new markets. To achieve this, however, the complex measurement technology must be made much smaller and more cost-effective,” explains Anna Kress, Director Technical Business Development at m2p-labs GmbH, who is supporting BICCell in the project-accompanying committee. However, this goal cannot be achieved with commercially available integrated circuits (ICs) because they are too expensive, too energy-intensive, too slow and, above all, cannot be integrated into a microtitre plate system, Kress continues.

iba and IMMS develop integrated circuit for relaxation spectroscopy

› Integrated sensor systems
› Distributed measurement + test systems
› Mag6D nm direct drives
› Contents
* Funding

In BICCell, IMMS will therefore develop a new IC that, in contrast to common impedance measuring devices, works with relaxation spectroscopy, a method established at iba. In this process, the time signal is evaluated that results from the excitation of the material under investigation with a step function.

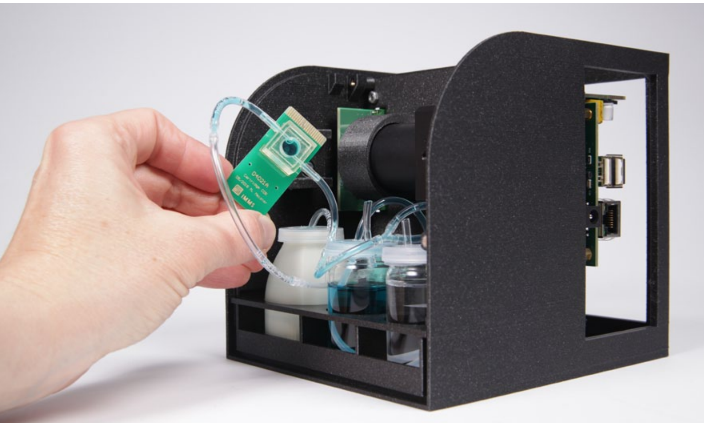
This method and in particular the theoretical principles for generating the excitation signal and sampling the response are the basis for the concept of the impedance measuring chip, which iba will contribute to BICCell. In addition, the practical measurements of the application examples will be carried out in iba's laboratories.

Chip to open up impedance spectroscopy for various applications

With the new integrated circuit, impedance spectroscopy can easily be transferred to different applications due to its high variability and thus be used universally. The installation space and costs of impedance measurement systems can be minimised with the chip. With this, a demonstrator will be designed and verified on two selected applications: the monitoring of cell cultures and the measurement of test strips. The SMEs on the project's accompanying committee can test the IC's suitability for their specific applications and develop prototypes from it after the project ends.

"With miniaturised impedance analysers, we can expand our systems with important additional information for cell cultures, especially for determining the live cell count, which is particularly important in cultures with mammalian cells. In the long term, we want to apply the research results from BICCell in our products," says Anna Kress for m2p-labs. Dr. Friedrich Scholz, Head of Development at Senova Gesellschaft für Biowissenschaft und Technik mbH and also a member of the BICCell project committee, explains that the project will provide important impulses for diagnostic development and, above all, relieve the burden on the healthcare system through early diagnoses. He predicts: "This technology promises to stand out significantly from current technology available on the market."

BICCell at www.imms.de.



With the modular hardware and software platform developed at IMMS, test setups, functional prototypes and demonstrators for integrated sensor systems for in-vitro diagnostics can be implemented quickly and cost-efficiently.

Photograph: IMMS.

Modular prototyping platform for integrated sensor systems for in-vitro diagnostics

IMMS researches and develops integrated sensor systems for use in in-vitro diagnostics. The work is characterised by a high degree of interdisciplinarity. Each integrated sensor system of IMMS is part of a superordinate diagnostic system in which the various components from different domains come together. Typically, these are optical and fluidic components, chemical and biological processes as well as other effects that have to be considered together, in addition to our electronics.

To be able to characterise our integrated systems and to test them close to the application together with our partners, we have developed a modular hardware and software platform with which test set-ups, functional prototypes and demonstrators can be implemented quickly and cost-efficiently. The basic idea behind the development of the platform was the realisation of a fast prototyping system with powerful modules in order to provide the functionalities typically required for in-vitro diagnostic applications.

On the hardware side, the platform includes functional modules for power and voltage supply, electrical signal conditioning, digital signal processing by means of FPGA and processor and also modules for controlling light sources, fluidics and heating elements as well as modern communications modules with wireless interfaces such as WiFi and Bluetooth for control and data transmission. The platform software covers the basic control of the hardware modules as well as the recording and processing of the measurement data. In addition, it enables the automated execution of measurement sequences, whereby predefined blocks can be used. The software has a convenient web-based user interface that can be used to interactively execute and compose sequences. In addition, direct access from our partners' applications is possible via a network-based programming interface (API).

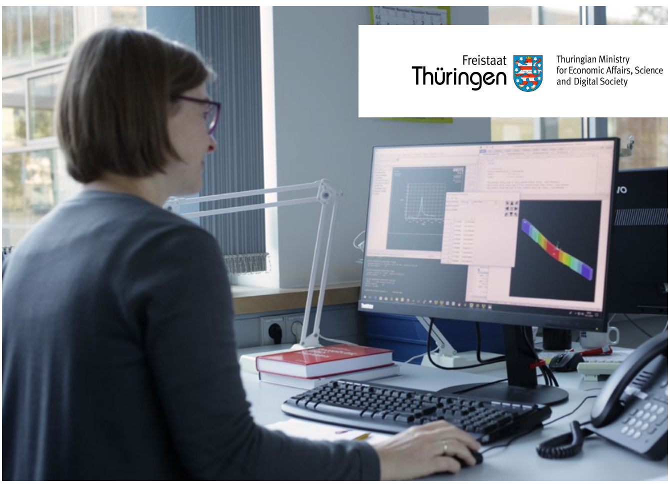
The platform was developed in the internal research group on integrated system solutions for life sciences applications.

MagSens* research group completed: Ultrasensitive magnetic field sensors with resonant magneto-electric MEMS

In the years from 2018 to 2020, IMMS conducted research in cooperation with Ilmenau TU on MEMS sensors for detecting weakest magnetic fields. Such fields occur, for example, in the human body, where they must be measured very precisely, without contact or destruction.

For this purpose, sensors based on superconductive quantum interference devices (SQUIDs) are used in medical technology as well as in geology, archaeology or materials science. However, these sensors have to be cooled to at least –196 °C with a very high cryotechnical effort in order to be operated at all.

As an alternative to this, magnetoelectric MEMS, which are comparatively easy to manufacture and are operated at room temperature, were investigated in the MagSens group led by Ilmenau TU. Corresponding test structures of the sensors have been produced at Ilmenau TU and measured at IMMS.



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

ANSYS simulation of the transmission behaviour of a magnetostrictive piezoelectric MEMS bar structure for research on MEMS sensors for the detection of the weakest magnetic fields.

Photograph: IMMS.

The researched sensor principle is based on magnetostrictive-piezoelectric multilayer systems. A resonator consisting of these layers is made to vibrate piezoelectrically by applying a voltage. The magnetostrictive layer changes the oscillation behaviour, or more precisely the resonator's natural frequency, under the influence of a magnetic field. The change in the natural frequency can be used to infer the strength of the acting magnetic field.

IMMS has taken over the modelling of the sensor principle and has analytically described the so-called Delta-E effect. This effect was identified as the decisive magnetostrictive effect. It describes the change of the Young's modulus of the magnetostrictive layer under the effect of a magnetic field. Further, the vibration behaviour of the sensor was simulated at IMMS in the FEM software ANSYS.

This was used to investigate the influence of material and geometry data on the sensitivity of the sensor. The aim was to find structures that react with a maximum frequency shift to the effect of the smallest magnetic fields. On the one hand, this required the optimisation of the magnetostrictive layer with regard to a Delta-E effect that is as pronounced as possible. This involves material data that are dependent on the manufacturing process of the layer. Together with the colleagues from the TU, possibilities were discussed to influence these data and initial steps were taken to design the magnetostrictive layer accordingly.

On the other hand, it was a matter of dimensioning the entire multilayer system in order to maximise the influence of the change in Young's modulus on the frequency shift. For this purpose, various fundamental geometries with variable aspect ratios were simulated and evaluated.

The test structures developed by the TU are cantilevers and double-clamped beams of different dimensions. These structures could be successfully simulated at IMMS. The simulation data coincided with the measurement results and were used for parameter identification of unknown material data. Based on this, design rules and guidelines for the development of variable magnetoelectric sensor systems were derived.

MagSens at www.imms.de.

In KI-EDA, AI tools for the fast and reliable design of customised encoder and sensor chips are being developed. Such systems are needed for novel intelligent autonomous production systems. Source: IMMS.

SPONSORED BY THE
Federal Ministry of Education and Research

Project launch of KI-EDA*: AI to design drive control chips as key products for Industry 4.0

On 24 March 2020, the partners iC-Haus, CENTITECH and IMMS met in a virtual kick-off event to discuss details of the three-year BMBF-funded research and development project „Artificial Intelligence for the Design of Microelectronic Drive Control Chips as Key Products for Industry 4.0 (KI-EDA)“, which started on 1 January 2020. The aim of KI-EDA is to harness the tools of artificial intelligence (AI) for the rapid and reliable design of customised encoder and sensor chips. Such microelectronic systems are needed for novel intelligent, autonomous production systems that can securely analyse data in a decentralised manner to predict and improve manufacturing scenarios.

Conventional design methods are usually not sufficient for complex and individual designs

Encoder and sensor chips are used, for example, to detect rotary movements on machines and convert them into electronic signals for digital processing. These chips are customised for production machinery and processes and are becoming increasingly powerful and complex. The design and verification of the chips is reaching its limits with conventional electronic design automation (EDA) methods and is largely shaped by the experiential knowledge of design engineers.

New methods should reduce the development time of customised chips by up to two thirds

This is why the KI-EDA project, which is being led by iC-Haus GmbH, is working on AI-supported methods of design automation and on a modular system for chip design. Individual functions should be able to be selected, combined and simulated quickly and cost-effectively in the form of function blocks with short design times and a low error rate, and transferred into an encoder or sensor chip customised for the planned application. Furthermore, this makes it possible to implement new functionalities such as AI-based predictive maintenance solutions flexibly and quickly. Errors in the design and thus time-consuming redesigns are to be reduced in this way. The aim is to reduce the development time of customised chips by up to two thirds.

To this end, the partners iC-Haus and CENTITECH will research and implement intelligent functions and energy-autonomous solutions for the new microelectronic systems and characterise them in application-oriented demonstrators. This is intended to ensure the properties required for widespread and comprehensive use in I4.0 production environments. In addition, the partners will ensure that the systems can be manufactured in high quantities.

IMMS transfers ML algorithms and smart models into modular system for fast and safe chip design

IMMS will research machine learning (ML) algorithms for their applicability in chip design (EDA) and transfer them into a novel designer assistance system to make design processes more efficient and faster. The new ML methods to be researched will primarily serve a fast design validation and thus increase design security. They are aimed in particular at model-based debugging and should reduce the complexity of working with IP libraries, i.e. with collections of existing circuit components or electronic blocks. New chips can thus be assembled in a modular system. In addition, IMMS will research and implement „smart models“. For the first time, new algorithms will enable models to computationally check their own range of validity and thus exclude false-positive verification results.

More on KI-EDA at www.imms.de.

IMMS co-initiated the edaBarCamps in 2016 and has been one of the organisers ever since. 2021 Georg Gläser from IMMS gave impulses for the selection of topics in his keynote talk “Artificially IntelligEnt EDA?!”.

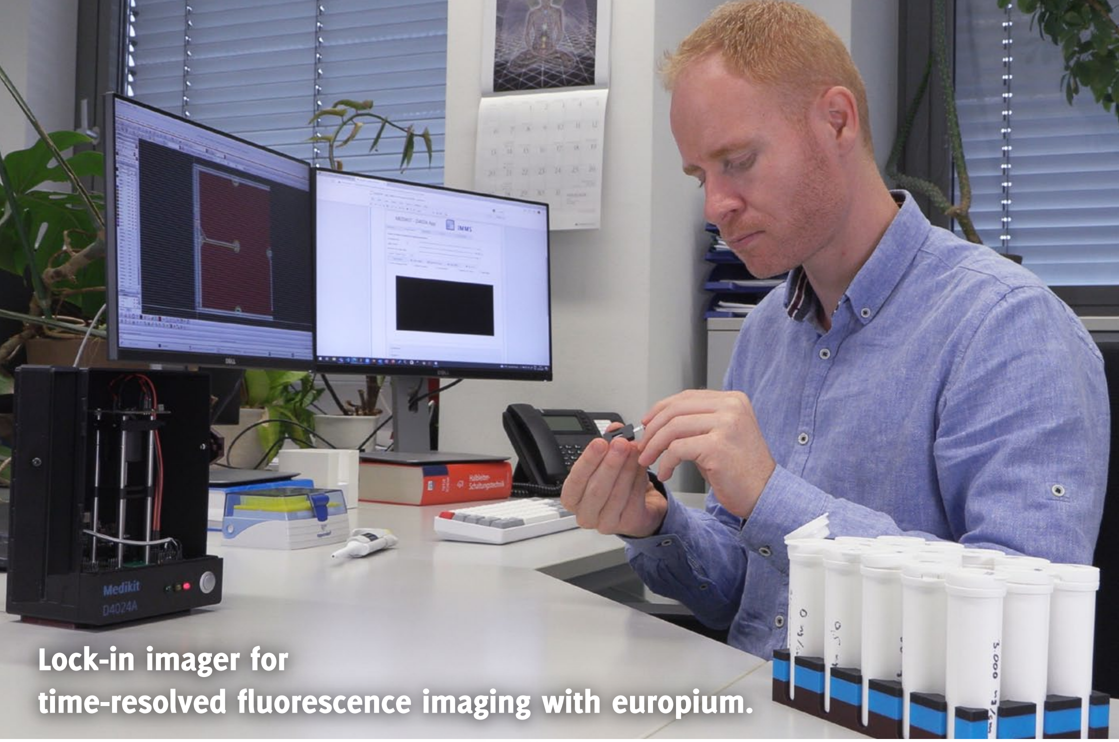
Source: edacentrum.

edaBarCamp – Number 5 is alive

On 18 and 19 February 2020, the 5th edaBarCamp took place at IBM Germany Research & Development. With 68 participants from industry and research, it was the largest edaBarCamp to date. It was organised by edacentrum, IBM, IMMS, OFFIS - Institute for Computer Science, Ilmenau TU and Carl von Ossietzky Universität Oldenburg. There was a wide range of input on design methodology and lively exchange on topics such as design verification for microelectronics, integrated circuits and embedded systems, integrated hardware/software engineering, artificial intelligence for electronic design automation EDA and more.

In the series of events initiated and organised by edacentrum, OFFIS and IMMS in 2016, interactive and open research meetings are regularly set up according to the BarCamp principle. At the edaBarCamp, people not only passively listen, but above all actively participate. Georg Gläser from IMMS gave impulses for the selection of topics for the 5th edaBarCamp in his keynote talk “Artificially IntelligEnt EDA?!”.

More on the edaBarCamp at www.imms.de.



Lock-in imager for time-resolved fluorescence imaging with europium.

IMMS has developed a lock-in imager chip for time-resolved fluorescence imaging with europium and integrated it into an example application for digital readout of strip tests. The picture shows the demonstrator. Photo: IMMS.

Motivation and overview

In in-vitro diagnostics, the labeling of target analytes with fluorescent dyes is becoming increasingly common, as they can be easily distinguished from background and interfering signals. In the MEDIKIT project, IMMS has developed a lock-in imager chip for time-resolved fluorescence imaging with europium and integrated it into an example application for digital readout of test strips. Those tests, also called lateral flow assays (LFA), play an important role in in-vitro diagnostics. They are cost-effective, easy to handle and therefore perfectly suited for decentralised and time-critical diagnostics. They are widely used as pregnancy or COVID-19 rapid tests, among others, to make qualitative conclusions (positive or negative). However, quantitative information on concentrations and ratios are needed for many diagnostic questions. Common LFA reader combinations with classical dye particles such as gold are not sensitive enough for this purpose. New LFA reader combinations with europium markers offer much higher readout sensitivities, which are supported by our imager. Thanks to its lock-in principle, elaborate optical filters can be omitted.

More on MEDIKIT at www.imms.de

Imager chip for measuring time-resolved fluorescence

The imager chip developed at IMMS uses time-resolved fluorescence to detect the concentration of biomarkers using molecular biological and immunological assays developed by our project partners Senova and Oncgnostics. The biomarkers bind fluorophores (such as europium in the example application with test strips) and these are excited with light of specific wavelengths. As a result, they emit photons of longer wavelengths, which are detected by the chip. In conventional fluorescence measurements, excitation and emission light are separated by optical filters. In time-resolved fluorescence measurement, the emission is detected only after the excitation light has decayed. Excitation and emission light are separated by their different temporal decay properties, cf. figure 1.

If the excitation light is switched off, its intensity falls within a few nanoseconds far below that of the fluorescent light of europium, which has decay times of several hundred microseconds. With the new image sensor of IMMS, the excitation light can be faded out in time and the fluorescence light is collected over several illumination cycles. This enables a very high sensitivity as well as a cost-effective system design for point-of-care diagnostic systems. Furthermore, the image sensor can also be used to directly measure the temporal decay curves, so that different fluorescent dyes can be simultaneously distinguished from each other, thus enabling multiparameter diagnostics.

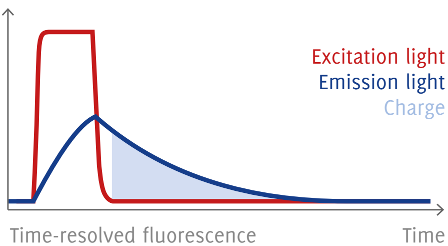


Figure 1:

Different temporal decay properties of excitation and emission light. The area under the blue curve corresponds to the charge of the emission light relevant for measurement.

Diagram: IMMS.

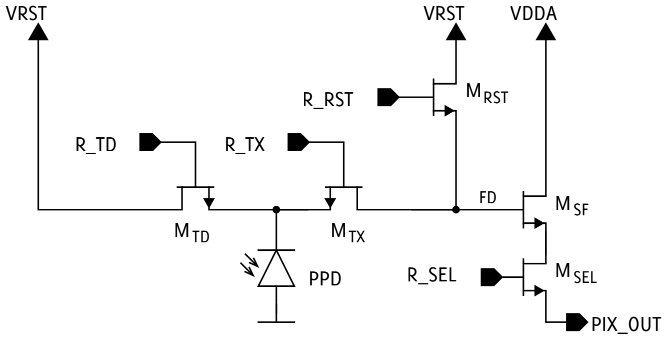


Figure 2:

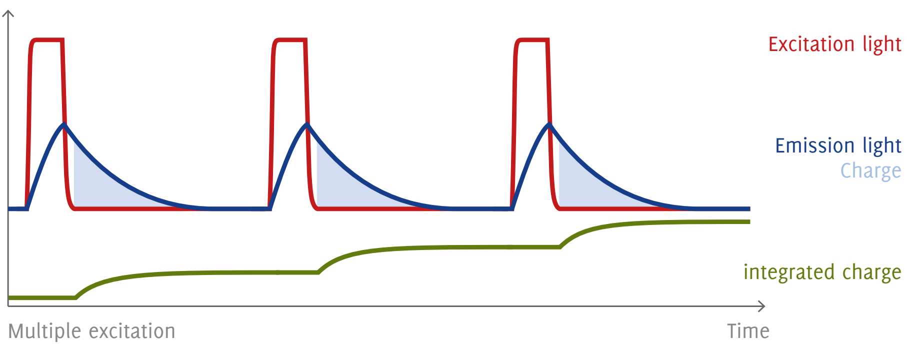
Simplified circuit schematic of the lock-in pixel.

Diagram: IMMS.

Image sensor lock-in principle

The image sensor is made up of pixels that operate based on the lock-in principle, cf. figure 2. This means that the photodiode (PPD), as a light-sensitive element in the pixel, contains several rapidly switchable taps (M_{TX}, M_{TD}) to separate the charge carriers generated by the incident light into different temporal components. As soon as the fluorescent dyes are excited by a light pulse, the excitation light can be largely suppressed by an appropriate pixel configuration (M_{TD} conductive). Once it has decayed, the tap in the pixel is switched (M_{TX} conductive) and the emission light that is supposed to be measured can be collected (accumulation takes place on the capacitance of node FD) until it has also decayed. This sequence can be repeated several times, cf. Figure 3. The signal components originating from the fluorescence emission light are accumulated cycle by cycle, thus amplifying the output signal. Subsequently, the accumulated charges in the pixel array are digitally converted row by row (using M_{RST}, M_{SF}, and M_{SEL}), and the image data is transmitted at the end of the capturing cycle.

Figure 3: Once the excitation light has decayed, the emitted fluorescence light is measured until it has also decayed. This can be repeated several times. The fluorescence emission light is accumulated cycle by cycle, increasing the output signal. Diagram: IMMS.



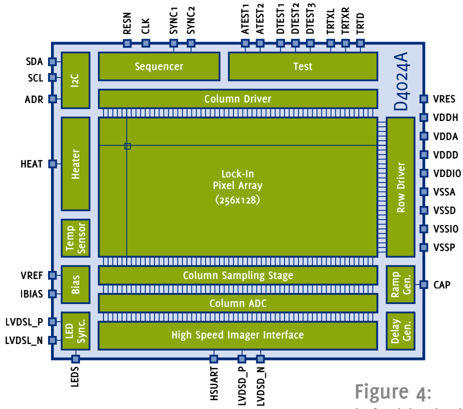


Figure 4:
left: block diagram; right: chip photo. Diagram/photo: IMMS.

Chip architecture

The image sensor shown in Figure 4 has a resolution of 256 x 128 pixels with a pixel size of 10 µm x 10 µm. This enables a variety of diagnostic applications, such as readout of LFA or direct spotting of DNA probes. Apart from the actual image array, the sensor also contains a single-slope analog-to-digital converter for the image data, a programmable sequencer for highly flexible control of the complete image acquisition process, an I²C interface for chip configuration and an analog temperature sensor.

Demonstrator

Based on the IvD rapid prototyping platform of IMMS, a demonstrator was developed for application-oriented evaluation of the new image sensor. The platform is housed in a 3D-printed case together with a pulsed light source for excitation of the fluorescent dyes, cf. Figure 5. The demonstrator provides a WLAN interface for wireless

More on this platform in this report.

Figure 5:

Demonstrator for the application-oriented evaluation of the new image sensor with the IvD rapid prototyping platform of IMMS. This is all built into the housing along with a pulsed light source to excite the fluorescent dyes.

Photograph: IMMS.

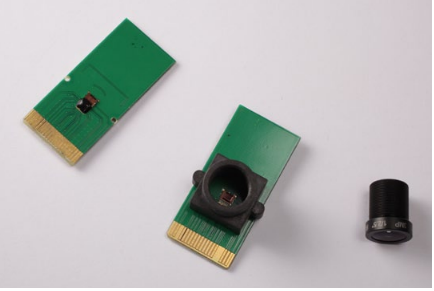
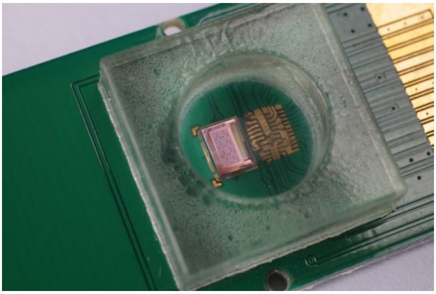



Figure 6: left: Cartridge with lens for readout of LFA; right: fluidic cartridge with cavity and biocompatible encapsulated sensor chip for molecular biology detection taking place directly on the chip surface. Photograph: IMMS.

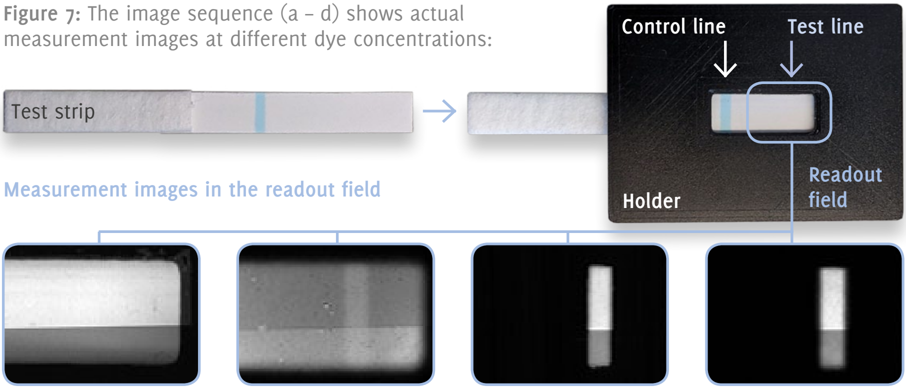
configuration of the sensor and image readout, through which the user interacts with the chip via a web browser.

The image sensor can be mounted on an application-specific cartridge that is plugged into the demonstrator. Two types were developed for this purpose in the MEDIKIT project: A cartridge with a lens for reading LFA and a fluidic cartridge with a cavity and a biocompatibly encapsulated sensor chip for molecular biological detection, which takes place directly on the chip surface, see Figure 6.

Evaluation

The LFA reader application works with an europium-based fluorescent dye that is excited with UV light. For the application-oriented evaluation of the image sensor, our project partner Senova provided standardised strip tests to which europium lines were applied in a concentration series. A very wide concentration spectrum with more than 4 decades (from 0.1 – 6000 ng/cm) could be detected with the chip, cf. Figure 7. This very high dynamic range is achieved by the multiple exposure mode described above, which allows to make the very low concentrations visible and still distinguishable from the background signal.

Figure 7: The image sequence (a – d) shows actual measurement images at different dye concentrations:



a) Ambient light:
0 Exposure cycles
0 ms LED-on time

b) 1 ng/cm
78 Exposure cycles
2.8 ms LED-on time

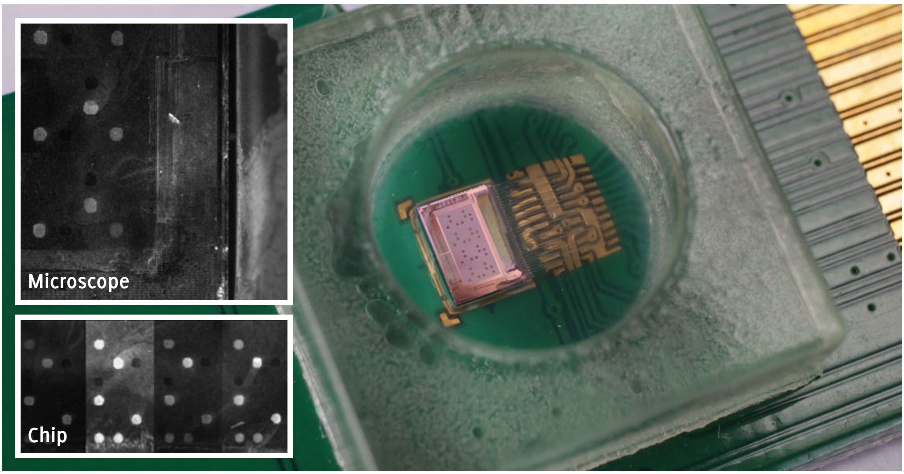
c) 50 ng/cm
1 Exposure cycle
2.8 ms LED-on time

d) 6000 ng/cm
1 Exposure cycle
23 µs LED-on time

(a) Reference image in ambient light *(without excitation light the fluorescence line is invisible)*, **(b)** at low concentrations *(translucent background with faint, noisy but distinct line at long exposure time and several exposure cycles)*, **(c)** at medium concentrations *(intensive line at long exposure time)* and **(d)** at high concentrations *(intensive line at very short exposure time)*. Photographs/Diagram: IMMS.

First promising results were also achieved with the fluidic cartridge. Our project partner oncgnostics was able to image an assay for the diagnosis of cervical cancer in the cartridge, see Figure 8. The target DNA could be clearly detected (figure 8 bottom), as the corresponding image through a fluorescence microscope (figure 8 top) shows.

Figure 8: Assay cartridge with measurement image of the lock-in imager chip (bottom left) and reference image of a fluorescence microscope (top left). Photographs: IMMS and oncgnostics.



The results from the investigations of the chip have already led to follow-up projects. In the Ovutinin* project with Senova, the chip will be adapted and further developed specifically for the LFA reader application. It will feature an adapted image array and a higher degree of integration. The goal of the project is to develop a commercial mobile LFA reader for fertility diagnostics.

The use for fluidic applications will also be further developed in the follow-up project "SensInt". Here, a derivative of the ASIC will be developed, which is directly designed for integration into a microfluidic chip with the partners microfluidic ChipShop GmbH und Axenoll 3D Printing GmbH.

Beyond these two projects, we aim to use the lock-in imager to pave the way for other applications for which time-resolved fluorescence is the key to industrial utilisation suitable for mass production.

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The project on which these results are based was supported by the German "Land" of Thüringen and co-financed by European Union funds within the framework of the European Regional Development Fund (ERDF) under the reference 2017 FE 9044.

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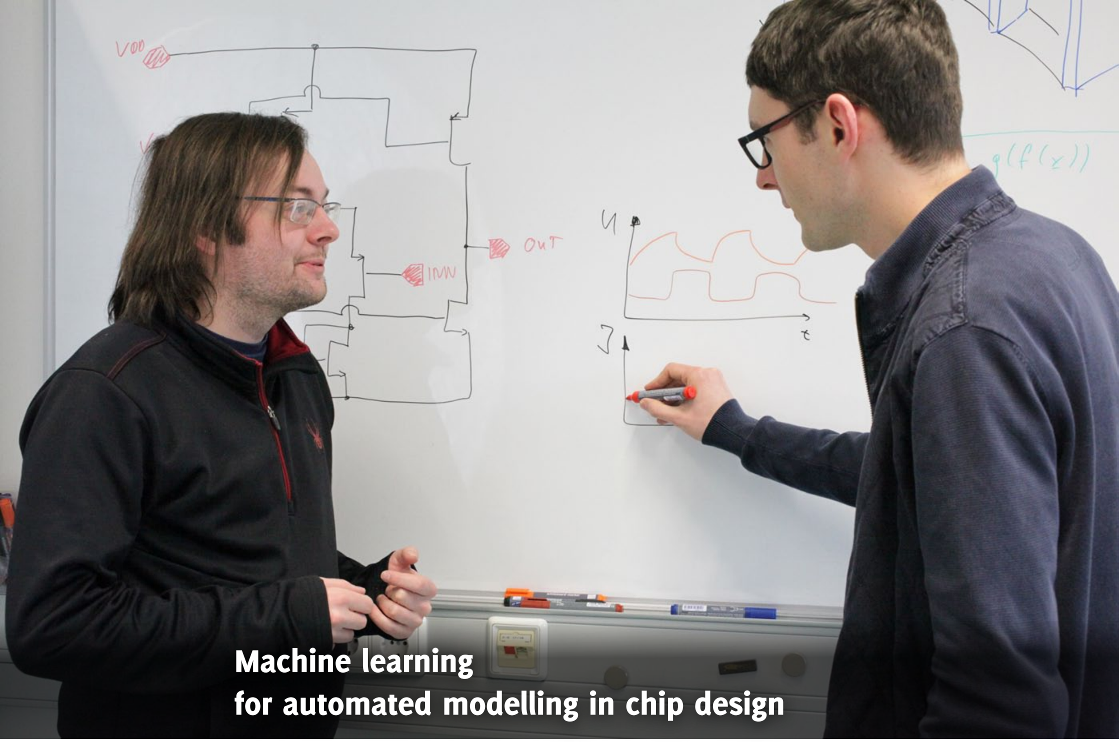


Machine learning for automated modelling in chip design

The methods for automated modelling in chip design developed at IMMS make system simulations more conclusive. Machine learning and neural networks significantly reduce the manual modelling effort. Photo: IMMS.

Motivation and overview

Today, microelectronic chips are made up of a wide variety of functional blocks. These are increasingly being integrated in such a way that complex applications in the automotive, industrial or medical technology sectors can be miniaturised more and more. Sensors, actuators, communications, energy management, microcontrollers, memory and other functions are combined on a single chip. The design of such systems is thus becoming increasingly challenging. Mixed-signal verification is therefore taking on an increasingly important role in the design: it uncovers errors in the interaction of the components and ensures that higher-level requirements for the product are met. This proof is usually provided by simulations of the complete design consisting of analogue and digital parts, including external circuitry. Simulations with SPICE models are the most accurate for this, but take far too long at the system level. In order to cover all required test scenarios during verification, faster and thus less accurate behavioural models must be used instead. Creating and adapting these abstract models for the respective verification task is time-consuming and requires a lot of experience. IMMS has therefore developed methods to automatically augment such models with additional properties and thus improve the validity of system-level simulations. Thanks to machine learning and neural networks, the manual modelling effort is significantly reduced.

Modelling concept

Behavioral models e.g. in VerilogAMS usually reflect the functional behaviour of individual circuit blocks or subsystems. If it is a self-developed block, the responsible design or verification engineer creates the corresponding model. If, on the other hand, it is a black box IP, it is mandatory to rely on the IP provider to make a model available. In any case, modelling has so far mainly been done by manual abstraction, for example by describing the input-output behaviour. So-called non-functional properties, such as power consumption, are usually not modelled because complex, non-linear dependencies to other system variables must be captured and mathematically described for this purpose. For certain designs, however, it is exactly these non-functional properties that are of essential importance. For example, the power requirements of the individual circuit blocks of an RFID sensor transponder IC must be taken into account during system verification.

IMMS has worked on these challenges in the IntelligEnt project and developed a modelling process. This learns such non-functional quantities from data using machine learning methods and thus significantly reduces the modelling effort to be

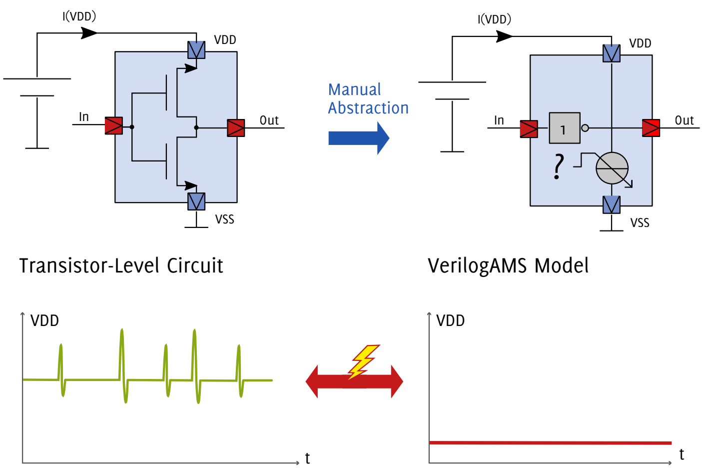


Figure 1:

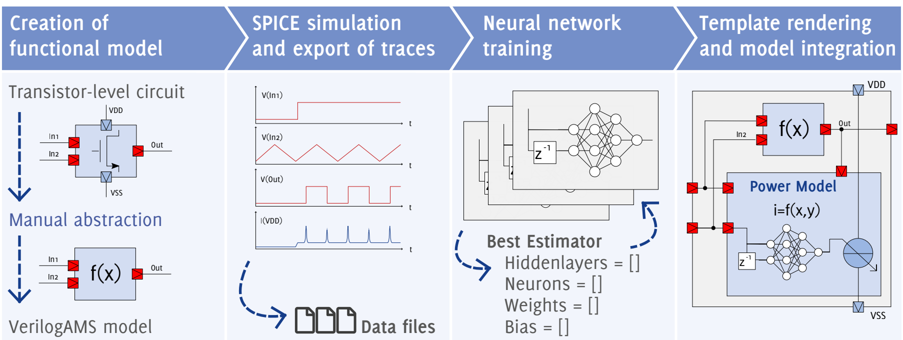
Non-functional properties are usually not integrated when creating behaviour models.

Diagram: IMMS.

Services on IC design methods: www.imms.de performed manually by the engineer. Specifically, neural networks were used as universal function estimators. To incorporate temporal correlations, networks were augmented with delay elements at the inputs, resulting in so-called time delay neural networks (TDNN). These networks can be evaluated efficiently in a digital event-driven simulation. Therefore, the resulting model can be simulated much faster compared to the transistor-level circuit, while non-functional properties are still represented with satisfying accuracy.

The prototypically implemented modelling flow is shown in Figure 2. Starting with the transistor-level implementation, an existing functional model is augmented with information about its transient energy consumption. For this purpose, SPICE simulations are first performed to characterise the energy consumption of the circuit. The data obtained from the simulation is then processed and converted into training data. The model is trained in a Python environment, since extensive libraries can be used for this purpose. The result of the training is a network topology selected by hyperparameter search as well as a parameter set optimised for it. In the following step, the network is exported to the design environment by generating Verilog code through template rendering. Using a Verilog rewriting tool developed at IMMS, the generated code can be automatically instantiated and connected in the existing functional model. The translation back to Verilog has the advantage that the model can be fully used with the existing design environment and no external software is required for simulation.

Figure 2: Modelling flow for automated extension of functional models with energy consumption information. Diagram: IMMS.



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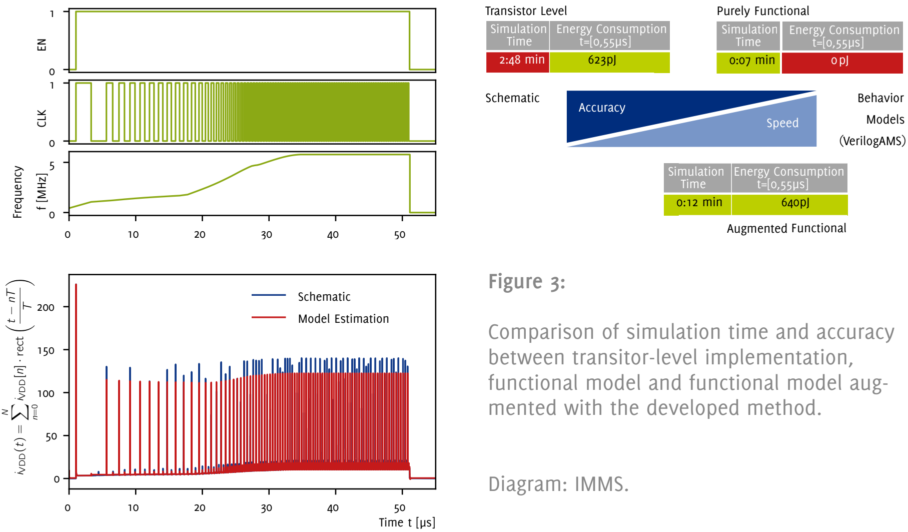

Figure 3:

Comparison of simulation time and accuracy between transitor-level implementation, functional model and functional model augmented with the developed method.

Diagram: IMMS.

Example: Modelling of a relaxation oscillator

The described design procedure was prototypically applied to the example of a relaxation oscillator frequently used as an on-chip clock source. To minimise the energy consumption of the digital part, the oscillator is only activated when a clock is necessary for operation. To include the power consumption of the oscillator in the system verification, the transient power consumption was added to a functional model. As shown in Figure 3, the extended model reproduces the power consumption sufficiently accurately, while the simulation time has increased only minimally compared to the purely functional model.

Example: Modelling switched capacitor circuits

Switched-capacitor circuits, for example in the case of charge pumps, are an essential part of the power management of memory IP or energy-autonomous sensor systems. However, current modelling approaches for this are focused on the design and are not suitable for the system level. At the same time, these circuits are very slow to simulate with SPICE models, which greatly affects the system-level simulation time. In contrast, with ML-based automated modelling, the average amount of load to be transported between capacitors and across system boundaries is estimated by a neural network for each clock cycle. In addition to the clock frequency, the load current and the current node voltages are inputs to the network. As shown

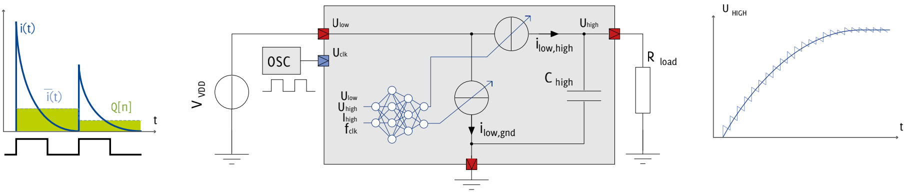

Figure 4: Example of a charge pump model based on charge transfer estimation. Diagram: IMMS.

in Figure 4, the estimated load transfer can be used to implement a real-number model. Using automated modelling, for the example of a three-stage charge pump, the charge transfer was estimated so accurately that there was a maximum 1% error in the output voltage compared to the SPICE model, while at the same time reducing the simulation time by a factor of 30.

Outlook

The application of the developed methods was successfully demonstrated in two scenarios, which were presented in two publications at scientific conferences. There is potential for further development at two points in the demonstrated procedure where currently manual intervention is still required. First, the selection of the input signals is crucial for the quality of the training data set. Here, an automatic analysis of the data should first identify the signals that have an influence on the target variables. On the other hand, the size of the neural network has to be determined manually or by a hyperparameter search. A heuristic to be found could make this process more efficient.

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At IMMS, we will follow up on the presented work by applying the results to the automated modelling of complex IP blocks such as embedded memories. There is a great need for such methods in this field, as memories are typically integrated by customers into their chip designs as black-box IP. In addition, automatically provided energy models can significantly increase design reliability and allow systems to be further optimised with respect to their energy requirements.

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The method is therefore also of particular interest to IP providers who intend to offer their customers application-specific behavioural models at attractive conditions.

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EUROPEAN UNION European Social Fund

Freistaat Thüringen

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„Trash or Treasure“ – artificially IntelligEnt layout processing

In the IntelligEnt research group, an AI-based anomaly detection method was developed that can automatically detect non-proven and potentially faulty locations in layouts. Photograph: IMMS.

Motivation and Overview

Design experience plays a major role especially in the geometric design of PCBs and chips. These last steps on the way to manufacturing require knowledge about which lines carry particularly sensitive or highly interfering signals and how these must be handled. In the case of ASIC design, heuristics for symmetries, special arrangements, etc. are added to this. Even textbooks give important advice here: “If something looks nice, it will work”. Quality assurance is often carried out here on the basis of heuristics, sometimes elaborate simulations and reviews.

AI-based algorithms have shown in various applications that they are capable of mapping such non-formal experiential knowledge. However, two important challenges arise when using them: First, a suitable data representation must be found that can be efficiently processed (and stored) while mapping all important information about the geometry and signal types. Furthermore, no pre-classified data is available for training: There is currently no open data set that contains typical fault cases in a representative way.

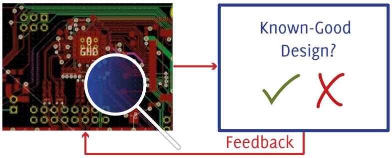

Figure 1:
The design and feedback loop in PCB design.
Source: IMMS.

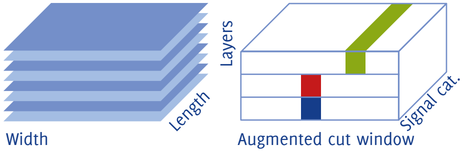

Figure 2: Layer-by-layer data representation (left) and cross-sectional representation which is used in IntelligEnt (right). Source: IMMS.

In the IntelligEnt research group, IMMS and Ilmenau TU have therefore developed an AI-based anomaly detection method that can automatically detect non-proven and potentially faulty locations in layouts. Through a flexible data representation, both PCB and ASIC layout data can be processed with this method.

Layout data too complex for ML training

In most cases, layout data are available as vector graphics in which the various objects are linked to manufacturing layers. However, in order to apply a machine learning algorithm, the data must be numerical, i.e. vectors, matrices or tensors. A simple mapping to a 3D numbering scheme that represents the different levels and retains all details is impractical: in ASICs, more than 50 levels can occur here. If signal properties are also to be taken into account, this representation leads to the data sets becoming extremely large and can thus hardly be used meaningfully for a training process.

Boil data down to the essentials

The IntelligEnt research group has therefore investigated a new approach: By taking cross-sections through the layout, the geometry can be represented by a 2D data schema (image), signal properties are added in the third dimension. This method is comparable to a colour image: the image itself (the brightness) shows the geometry, while the colour channels are used for signal properties such as categories. However, care must also be taken here to ensure that the resolution of the cross-sections or images is high enough to show all the details of the layout. For this purpose, the minimum structure size, for example, can be used as a guideline for accuracy.

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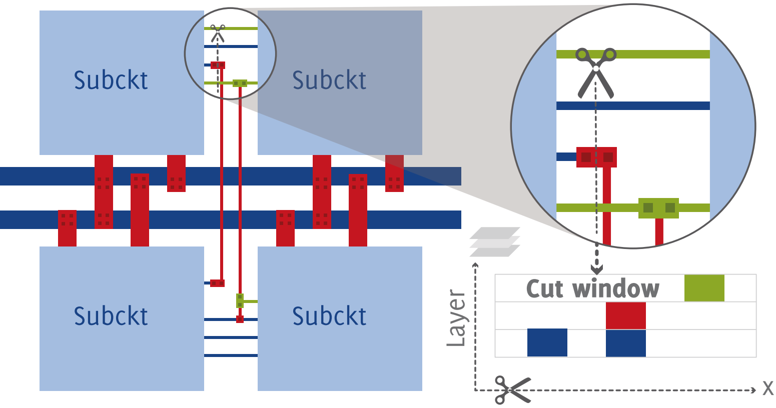

Figure 3:

Layout pre-processing: The layout is cut along a cutting line and assembled into a corresponding “image”.

Diagram: IMMS.

Autoencoder – neural network discriminates good and bad designs

The core idea of the machine learning algorithm is to detect deviations from a given data set. This means that deviations from design rules used there are to be recognised on the basis of known good designs. The assumption is that there is an example data set in which mostly good design practices have been used. An autoencoder is used for anomaly detection. This neural network is based on the idea that an input data set is mapped onto itself as if through a bottleneck or the lens of a camera. The image information is thus compressed and cropped. This creates a reduced representation that is compared to the input data. The mapping error will be very small for data that resembles the training data, while it will become larger for data that deviates. It can therefore be used as a measure of the deviation from the training data set – and thus of the deviation from the design principles used in the process.

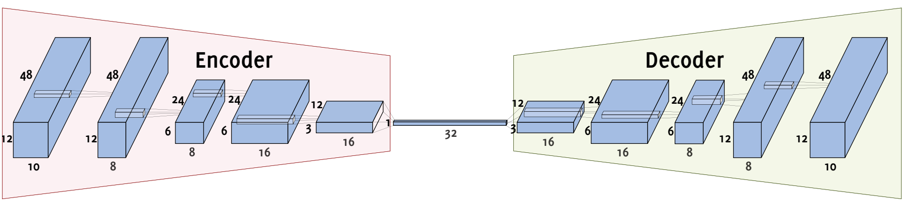

Figure 4: The architecture of the applied AI system (autoencoder). Diagram: IMMS.

Processing ASIC Layouts

Analogue-to-digital converters (ADC) pose particular challenges to the layout: especially, symmetries must be maintained and, for example, crossings of digital switching signals and analogue measured variables must be avoided. At IMMS, for example, ADCs are being developed that work according to the principle of successive approximation (SAR ADC). The layout of such an ADC is available in two versions: In the first step the layout was created by an inexperienced engineer and in the second step it was revised by an experienced layouter.

The layout of the experienced layouter was used to train the algorithm shown. For this purpose, the different signal lines were divided into categories, which were inserted in the "colour channel" of the cross-sections. After training the shown autoencoder, it was used to examine the first layout variant. The resulting reconstruction errors were marked in colour in the layout in a heat map in figure 5, with red areas representing places with larger reconstruction errors.

It turns out that the algorithm has marked exactly those areas that were strongly adjusted in the revision in order to improve the performance of the transducer. In addition, the error locations can be automatically divided into different categories, which are to be examined more closely and improved in future analyses.

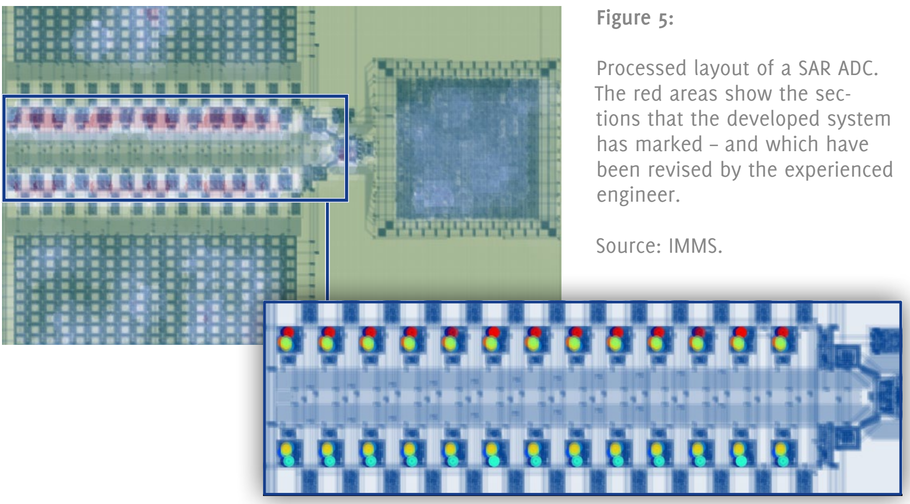

Figure 5:

Processed layout of a SAR ADC. The red areas show the sections that the developed system has marked – and which have been revised by the experienced engineer.

Source: IMMS.

In addition to these detected anomalies, isolated artefacts occur that can be addressed in an overarching one. If the system is applied to several designs in this way and the training data set is expanded with the "good" designs in each case, it is expected that the recognition accuracy will increase and possible defect locations can be recognised in an increasingly targeted manner.

Processing PCB Layouts

The IntelligEnt research group supervised a student software project at the Ilmenau TU in which the anomaly detection method was developed as a plugin for the free PCB design tool KiCad. With the plugin, signals can be categorised in KiCad and transferred to the training or evaluation process. The system was designed in such a way that the design data at the user's site is reduced to the cross-sections necessary for the autoencoder and then transferred to a central server for processing. Thus, on the one hand, a possibly necessary graphics processor is only required in the server and, on the other hand, the designs of several users can be combined.

For a first training, open-source designs were used, among others from the Crazyflie and HackRF projects. The signals of the designs were divided into categories and transferred to the programme. For evaluation, the signals shown in the figure were modified so that they should be recognised by the anomaly detection: For example, a clock line was routed over a sensitive RF part.

The evaluation shows that the built-in faults were correctly detected. Occurred artefacts or false positive regions, which are supposedly faulty, can be explained, for

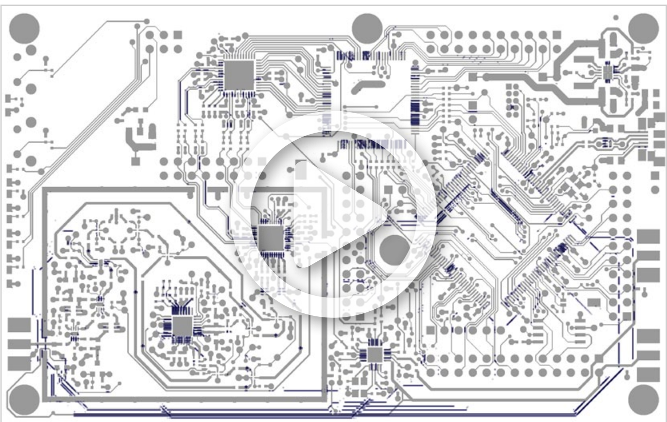

Figure 6:

As an example, error locations were inserted into the open-source layout of the HackRF project. The anomalies found (in blue) mark these modifications.

Source: IMMS.

Download the Plugin at GitHub

Watch the video tutorial on the plugin example, by the fact that they were underrepresented in the training data set. However, this effect should be reduced or even disappear completely after an expansion of the training data set.

Outlook

The developed method for anomaly detection on layout data was demonstrated in two different scenarios. It can be used to detect deviations from good design practice in both ASIC and PCB design. Currently, however, only signal information in terms of signal categories (analogue, digital, clock signal, etc.) is mapped in the algorithm for this purpose. A combination with simulation or measurement data could greatly improve the accuracy of the method – and also simplify handling, as this information does not have to be entered manually.

An extension to other layout types such as MEMS layouts is just as thinkable as an adaptation and improvement of the machine learning methods used. Through e.g. additional classification, the exact error case could be identified and thus hints for rectification could be given. A combination with automatic layout algorithms is promising, as they can be given almost "human" design experience.

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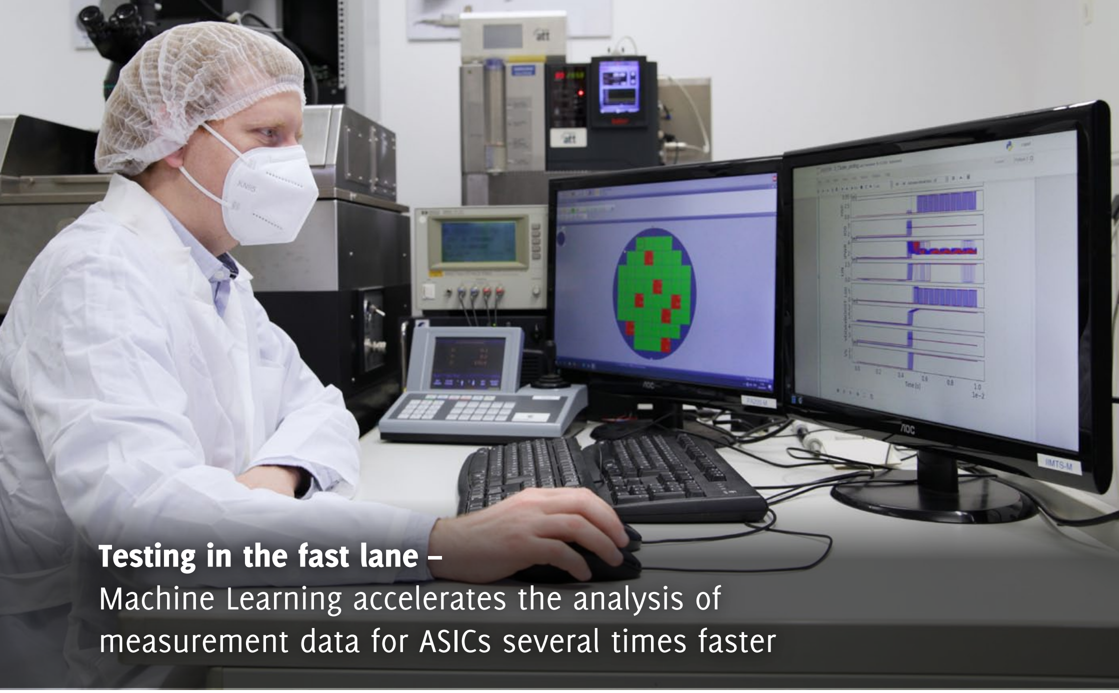

Testing in the fast lane – Machine Learning accelerates the analysis of measurement data for ASICs several times faster

IMMS has developed a machine-learning-based method for analysing measurement data from ASICs. It delivers the same results as a manual evaluation, but is 10 – 30 times faster. Photo: IMMS.

Motivation and Overview

Whether newly designed integrated circuits (ICs) are operating as intended and can hence be mass-produced is examined in detail with characterisation and test procedures. Automated test setups already exist for this purpose which are applied to mixed-signal chips and MEMS – to check the specified operating conditions. However, if it is necessary to identify where and how an IC begins to fail, test procedures must be performed outside of the specification. This generates extensive amounts of measurement data. These usually contain a high number of potential faults which have to be examined separately in a manual manner, resulting in a very time-consuming and cost-intensive process. For such test data analyses outside the specification, IMMS and Ilmenau TU developed a new method based on a machine learning algorithm. With this method, similar occurrences of faults and failure symptoms can be grouped automatically. The method was evaluated in a case study with an industrial test data set for a chip from Melexis GmbH. The automatically generated groups efficiently clustered the similar behaviours during potential failure scenarios, provided representative examples as well as data visualisations to the user, and thus reduced the time required by a factor of 10 to 30 compared to that of the expert.

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With out-of-spec tests, thousands of potential failures are possible

A possible fault is recorded during a measurement if the test system measures signal values that are outside the expected value range. These locations are stored with the time and the triggering measured value, so that this deviation can be analysed manually later by an engineer using transient signal data.

For tests performed within the specification of a circuit, this type of evaluation does not cause any problems, as these usually produce none or only a small number of failures. However, if measurements are also made outside the specification, individual causes of faults are often marked on numerous occasions. Thus, it is quite possible that a series of measurements in its entirety contains several thousand potential failures.

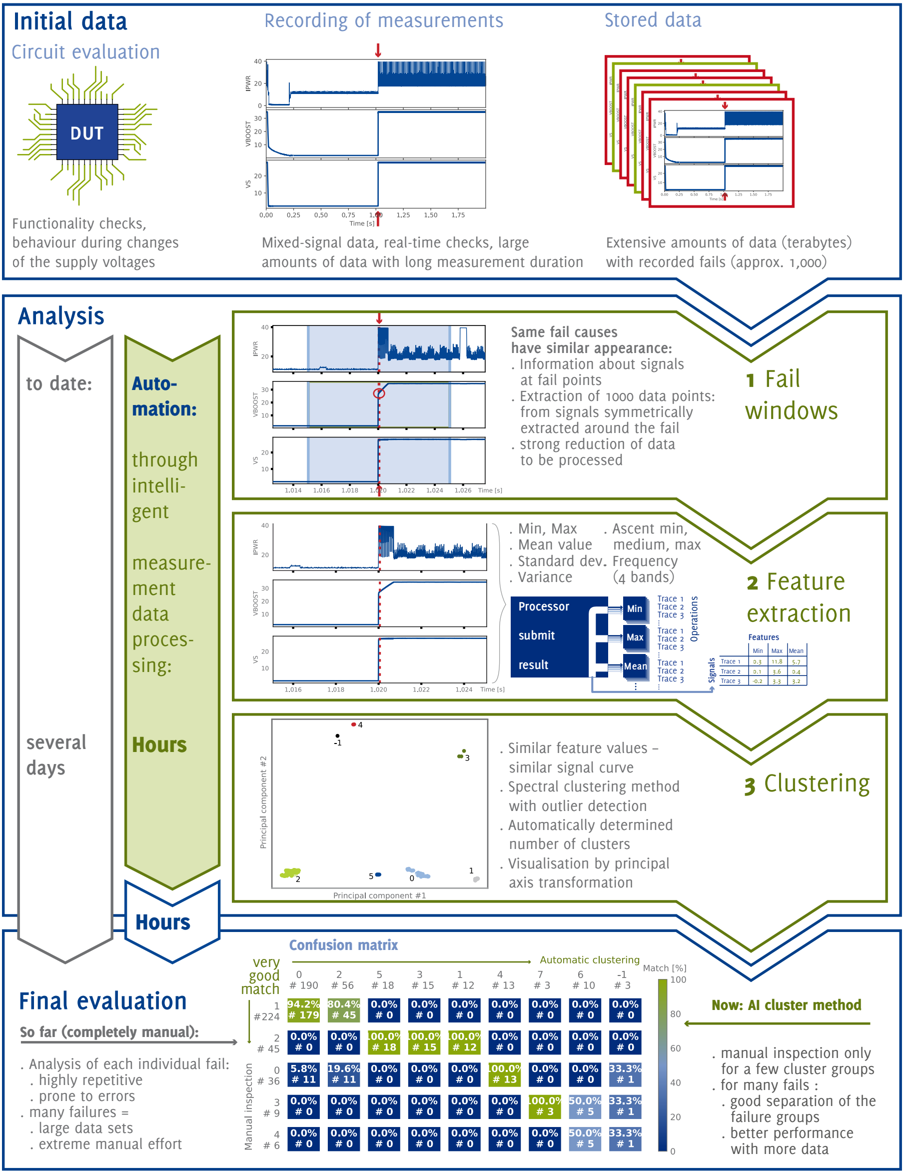
A test engineer would then have to deal with the very time-consuming process of analysing each of these markings and assigning a cause. The algorithm developed at IMMS for pre-sorting these recorded signal deviations is based on the fact that the captured failure markings of a same cause are very similar to each other in its transient measurement data. To group these similar signals, expressive values must be generated, which can then be used to calculate groupings by a cluster algorithm. In this process, some attributes, also called features, are determined from the signal data for each recorded signal deviation, which together contain essential information about the curve sequences at the possible defect locations.

Sections of the signal data in the region of the fault marks are first separated from the data (Fig. Section 1). The subsequent calculation of statistical features (Fig. Section 2) from these extracted signal section generates the required features for each location of a potential fault. These features consist of variance, standard deviation and frequency components of the sections as well as their minima, maxima, mean values and their derivatives. These values are freely configurable and are calculated for each of the signals. Depending on the number of recorded measurement signals, 50 to 100 features are calculated for each signal mark.

Clustering via machine learning reduces number of cases for manual analysis

Using clustering algorithms from the field of machine learning, the recorded markings can now be sorted into groups using the data of the calculated features. The evaluation of several methods showed that the cluster algorithm DBSCAN (Density

Overview of the newly developed machine-learning-based method for ASIC measurement data analysis. Diagram: IMMS.



Manual inspection \ Automatic clustering	0 # 190	2 # 56	5 # 18	3 # 15	1 # 12	4 # 13	7 # 3	6 # 10	-1 # 3
1 #224	94.2% # 179	80.4% # 45	0.0% # 0	0.0% # 0	0.0% # 0	0.0% # 0	0.0% # 0	0.0% # 0	0.0% # 0
2 # 45	0.0% # 0	0.0% # 0	100.0% # 18	100.0% # 15	100.0% # 12	0.0% # 0	0.0% # 0	0.0% # 0	0.0% # 0
0 # 36	5.8% # 11	19.6% # 11	0.0% # 0	0.0% # 0	0.0% # 0	100.0% # 13	0.0% # 0	0.0% # 0	33.3% # 1
3 # 9	0.0% # 0	0.0% # 0	0.0% # 0	0.0% # 0	0.0% # 0	0.0% # 0	100.0% # 3	50.0% # 5	33.3% # 1
4 # 6	0.0% # 0	0.0% # 0	0.0% # 0	0.0% # 0	0.0% # 0	0.0% # 0	0.0% # 0	50.0% # 5	33.3% # 1

Based Spectral Clustering for Applications with Noise) is best suited for this application of failure analysis. On the one hand, this algorithm does not assume fixed numbers of groups. On the other hand, it is also beneficial due to the noise detection, which automatically marks those recorded markings as noise or as outliers that have an individual appearance in the measurement.

The result of the clustering can then be visualised in various ways. A display of the overlain curves of a group is suitable for causal research. This makes it possible to quickly identify whether all markings assigned to this group originate from a possible cause of error. Another view can be generated by the principal component analysis (PCA) of the 50 to 100 features. The PCA calculation makes it possible to combine all these features in such a way that they are displayed on only two dimensions (Fig. Section 3). Each cluster is assigned a colour. In this way, a clear group differentiation can be recognised.

Furthermore, this representation makes it possible to quickly identify correlations between several groups. For example, faults with similar causes that have been divided into different groups can be quickly identified, as they appear close to each other in this representation.

The possibility of annotating individual markings or entire groupings subsequently also supports and accelerates the documentation and evaluation of the measurement data. The computer-assisted evaluation of chip measurements thus drastically simplifies the effort of manual evaluation.

Evaluation on measurement series from industry

This process was evaluated using several measurement series from Melexis GmbH. One of the results was that a measurement in which 320 failures were recorded was divided into eight groups and three outliers by the cluster algorithm. Due to the structure of the designed algorithm, it is possible in retrospect to easily understand the sorting of the cluster procedure. The manual effort is thus reduced from originally 320 sections of the measurement to be evaluated to eight groups and three outliers, i.e. in total to 11 cases for evaluation. Therefore, for this example, it can be expected that the evaluation will be accelerated by about 10 to 30 times with the help of the presented algorithm.

Machine learning provides the same results as manual evaluation and is 10 – 30 times faster

For a comparison of the new and conventional evaluation procedures, the 320 fails were also examined manually and independently of the presented clustering procedure.

In doing so, it has been evaluated how accurately the grouping of the manual evaluation corresponds to the automated clustering procedure. This can be visualised with the help of a confusion matrix (bottom of figure). This compares the number of matches of the two techniques by adding up the assignment of errors from the evaluation techniques. These are then mapped in a matrix sorted by group size. Horizontally, the result of the automatically created clusters is shown and vertically, the manual grouping is shown.

It is clearly recognisable that the cluster procedure determines the same groupings as are found in the manual evaluation. The case that in the horizontal direction several clusters (5, 3 and 1) were assigned to one group in the vertical (2) direction shows that a cause of error can also have several appearances in the transient signal course. In a subsequent examination of the fault causes by an expert, these groups could be combined without any problems. In addition, three errors were assigned to the group "-1" or as detected noise in the automated procedure. These three cases are outliers and must subsequently be evaluated separately.

The developed cluster procedure with machine learning can extremely minimise the manual effort for measurement data evaluation of chip tests with large numbers of errors. In the example, only eight groups plus three outliers would now have to be analysed with the evaluated measurement data instead of the complete fail count of 320.

The presented method was developed by IMMS with the support of Ilmenau TU in the "IntelligEnt" research group.[1] Due to the results, which were evaluated with industrial, real measurement data and results of Melexis GmbH, it is only a small step to the actual implementation. In the next step, the fundamental principles will be transferred to industrial applications.

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1 T. Reinhold, M. Seeland, M. Grabmann, C. Paintz, P. Maeder and G. Glaeser, **"Ain't got time for this? Reducing manual evaluation effort with Machine Learning based Grouping of Analog Waveform Test Data,"** *ANALOG 2020; 17th ITG/GMM-Symposium, 2020,* pp. 1-6, https://ieeexplore.ieee.org/document/9257338

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RESEARCH FIELD

SMART DISTRIBUTED MEASUREMENT AND TEST SYSTEMS

Supported by:

ZIM Zentrales Innovationsprogramm Mittelstand

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

For future sensors and systems for measuring and testing that can validate, process and evaluate data automatically, IMMS is researching solutions for intrinsic intelligence directly in the devices. In the Trib.US project, IMMS and SONOTEC GmbH are developing a mobile device that supports inspectors in their maintenance decisions on transport rollers and helps reduce downtimes in production. The picture shows preliminary tests at IMMS. Photograph: IMMS.

Research field: **Smart distributed measurement and test systems**

› *Integrated sensor systems*
› *Distributed measurement + test systems*
› *Mag6D nm direct drives*
› *Contents*
* *Funding*

Integrated sensor ICs represent the heart of sensor and measurement systems. These can be wireless sensors, handheld diagnostic devices or high-performance stationary device solutions for machine monitoring, for example.

For increasingly performant sensors, we are working on the following research questions

Increasingly performant sensors and their rapidly expanding number lead to immense amounts of data, which are ever more pushing previous technologies to their limits when it comes to transmitting, processing and using them. Therefore, it will be necessary to design systems for sensing, measuring and testing in such a way that they can validate, process and evaluate data automatically in the future. We intend to achieve this by directly incorporating intelligence into the devices. Interconnecting these systems creates the possibility of distributing the tasks in the network. However, new challenges arise in the form of dynamic aspects due to network protocols and changing tasks over time.

In this research field, we therefore focus on three questions: How can sensor data be automatically processed into usable information as close as possible to the point of origin in a fast, cost-effective and energy-efficient way? What additional information can be obtained with the help of distributed sensor systems? How can such a system be modelled based on different subsystems in order to evaluate energy requirements, the optimal distribution of functionalities in the network and the influence of topology decisions?

With our solutions we address the following applications:

To address our research questions, we work on the one hand on the analysis of distributed IoT systems in order to implement energy- and resource-optimised embedded systems, for example for the "Internet of things" (IoT) or autonomous sensor networks for environmental monitoring or smart city applications. On the other hand, we conduct research on embedded artificial intelligence (AI) in order to be able to efficiently implement AI algorithms on highly resource-constrained systems, e.g. for automation technology and Industry 4.0.

Projects in this research field

In the field of real-time data processing and communications, we optimise embedded systems for signal processing and data transmission in real time so that, for example, connected, spatially distributed edge AI systems can communicate smoothly. In addition, we develop concepts and implementation architectures for modular and mobile test systems. With these modular hardware-software platforms, integrated circuits and embedded systems for various applications can be tested and characterised extensively, yet quickly and flexibly.

Highlights of 2020 in our research on smart distributed measurement and test systems

Project launch of Trib.US* – mobile multi-sensor inspection device for conveyor belt maintenance

Trib.US at www.imms.de

No branch of industry can be imagined without rollers in conveyor belts. If a belt comes to a complete standstill because of a defective conveyor roller, an entire plant can shut down. It is important to detect wear on such rollers in time to prevent downtime costs. However, the problem is that a single belt consists of a large number of rollers and these are installed in such a way that they cannot be checked easily or only at great expense. In Trib.US, IMMS and Sonotec GmbH are therefore developing an integrated mobile solution that supports inspectors in making maintenance decisions on transport rollers.The goal is a portable device with which the maintenance technician can precisely locate defects in order to reduce or prevent downtimes in production.

The device will use ultrasonic and speed sensors to detect deviations in the signals that distinguish defective transport rollers from those running normally. The development will make it possible to use correlation and sensor data fusion to draw conclusions on the location of the defect and display this information directly to the inspector in real time on his portable device. This makes it possible to check during operation, to immediately identify a defective transport roller and, in the event of bearing damage, to remove it in a targeted manner.

For this purpose, IMMS is developing the real-time capable platform as well as the algorithms for signal evaluation and correlation, while its partner Sonotec GmbH is developing the ultrasonic sensor technology and implementing the user interface as well as the associated management software for the maintenance staff.

For the EdgeCam solution, several networked multi-cameras will work together to create safety zones around mobile cranes and warn crane operators of potential hazards. Photo: ArtisticOperations/Pixabay.

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

Start of the EdgeCam* project – virtual safety zone for mobile cranes

EdgeCam at www.imms.de

In the EdgeCAM project launched in 2020, we are working with our partner emsys GmbH on the development of a virtual safety zone around mobile cranes.

Virtual safety zones have so far only existed in the form of light barriers or with the help of additional hardware that endangered persons have to carry with them. This makes them difficult to use in mobile applications. This is especially true for truck-mounted loading cranes, which are often used on-site by customers, where it is not possible to tag passers-by beforehand.

Therefore, we are developing a solution in which several networked multi-cameras work together to establish the safety zone and warn the crane operator of potential hazards. To achieve this, emsys and IMMS are initially developing a modular hardware platform that will be set up with different cameras and communications modules. The goal is to smartly select from different communications options the one that is most suitable at the respective location and for the current task.

Installation of a microclimate measurement network in an orchard of the Erfurt Teaching and Research Centre for Horticulture in the regional EXPRESS experimental field. Photograph: IMMS.

With support from
Federal Ministry of Food and Agriculture
by decision of the German Bundestag

Project manager
Federal Office for Agriculture and Food

EXPRESS* – Monitoring microclimate and drought stress in fruit growing

In July 2020, IMMS, as one of four partners in the regional "EXPRESS experimental field for data-driven networking and digitalisation in agriculture", installed the prototype for a microclimate measurement network in an orchard of the Erfurt Teaching and Research Centre for Horticulture. This will first determine local changes in air temperature and humidity compared to a remote weather station, as well as leaf moisture, and at the same time determine the most favourable measurement position for these parameters. For this purpose, IMMS deployed sensors in pairs in the orchard to enable a direct comparison in each case between a position directly on the tree or slightly away from it. These measurements were continued until autumn 2020. After that, IMMS optimised and expanded the microclimate measurement network for further questions.

Work is part of the regional EXPRESS experimental field

In the central German experimental field EXPRESS, the Helmholtz Centre for Environmental Research – UFZ, the Fraunhofer Centre for International Management and Knowledge Economy IMW and IMMS are working on the fundamentals for the interaction of existing technical infrastructures with new technologies and methods in farms under the leadership of the Institute for Business Informatics at the Leipzig University.

EXPRESS is aimed primarily at crop production, with a particular focus on special crops. Digital technologies should increase resource efficiency, support environmentally friendly production and preserve biodiversity in the long term. Innovative technology such as sensor technology, blockchain, virtual reality, field robots and 5G applications will help to shape new value chains and optimise production processes. In EXPRESS, potentially suitable technology is tested in cooperation with farmers and presented to the industry.

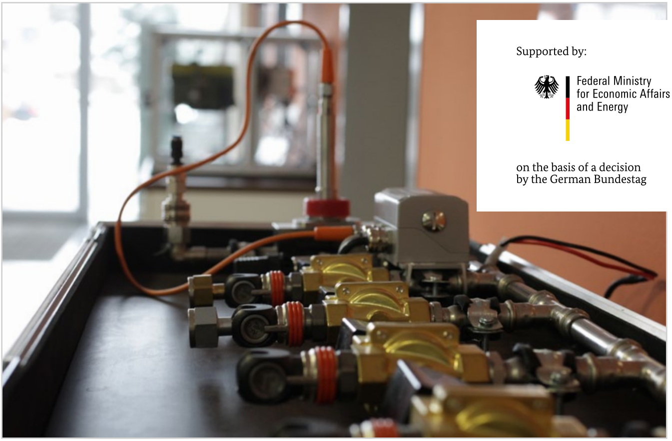
IMMS supports monitoring of microclimate and drought stress

In EXPRESS, IMMS is responsible for data collection and takes care of determining the microclimate and other parameters for monitoring drought stress. Different system solution concepts for these two applications are to be presented to agricultural enterprises. To this end, IMMS is testing various sensor systems available on the market for their suitability for the two focal points. In addition, IMMS equips the experimental fields with suitable sensor technology, monitors their operation and the transmission of the data via 5G to the S2DES cloud.

IMMS develops cost-efficient autonomous sensor systems for practical use

IMMS developments focus on autonomous sensor systems that are suitable for practical use. These are designed to be as modular as possible so that they can be adapted to the respective boundary conditions in an agricultural operation and used there for further analyses and optimisations. The challenge is to develop cost-efficient systems that record all the required variables with sufficient accuracy and at the same time enable usable conclusions with a high practical value using as few measuring points as possible.

EXPRESS at www.imms.de



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Mittelstand-Digital

“Mobile compressed air monitoring and energy monitoring” – one of 4 solutions created by IMMS in 2020 for demonstration purposes in the SME 4.0 project. Photo: IMMS.

Activities of IMMS in the “SME 4.0 Competence Centre Ilmenau “* (SME 4.0)

Demonstrators and projects for know-how transfer

In its role as “Migration Model Factory” in the “SME 4.0 Competence Centre Ilmenau” (SME 4.0), IMMS uses demonstrators and implementation projects to show small and medium-sized enterprises how they can introduce step-by-step digitisation solutions. In 2020, four solutions were implemented and accompanied by publications.

The transportable demonstration case “**Mobile compressed air monitoring and energy monitoring**” can be used to demonstrate various compressed air leakage situations. Leaks can be identified with a mobile ultrasonic detector. By measuring the energy consumption at the compressor and the volume flow of the consumed compressed air, the economic damage caused by each individual leakage is illustrated.

The demonstrator “**Ethernet QS**” shows how Ethernet cables placed in machinery can be monitored during operation. These cables are heavily stressed during constant movement in drag chains, for example. Gradual wear is often detected too late and leads to unplanned and sometimes long machine downtimes. With Ethernet-QS, errors in communications and defects are detected at an early stage by means of a permanent test that does not interfere with the actual data flow in the machine, and can be eliminated in time in the sense of predictive maintenance.

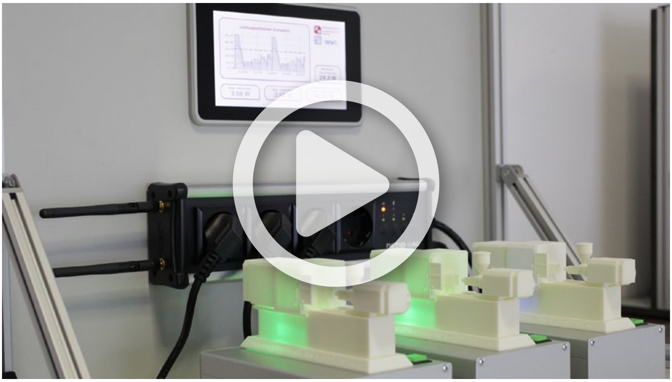
In the "**In-process quality assurance in machining**" project, a machining centre was equipped with retrofittable sensor systems, such as multi-axis vibration sensors, a laser vibrometer and laser interferometers, together with the partner GFE Gesellschaft für Fertigung und Entwicklung in Schmalkalden. The aim of this work was to investigate which sensor systems are suitable for recording critical machine parameters that affect the quality of workpieces during production. In addition, conclusions about the condition of the tool, such as the wear of a milling cutter, were to be made possible.

The "**EASY**" demonstrator shows how the causes of downtimes can be detected and thus how measures can be taken to ensure smooth production. For this purpose, the operating states of an injection moulding machine in the plastics industry were detected and recorded at the machine status light. The data can be used to derive statements on the number of pieces produced, production downtimes, reaction times in the event of downtimes, adherence to production priorities and the evaluation of process stability. The data is transmitted from the machine to a cloud solution via a low-cost IoT gateway that can be retrofitted without much effort. This means that machine condition data can now also be evaluated in the cloud across locations with existing plants that have been made Industrie-4.0-capable relatively easily.

More on SME 4.0 at www.imms.de.

Launch of AI trainer offerings

Since May 2020, AI trainers from SME 4.0 have been supporting the planning and design of concrete AI implementation measures and strategies. They impart knowledge on machine learning methods and other areas of artificial intelligence. They also help with the conception, introduction or expansion of digitalisation solutions with AI. The AI trainer of the Migration Model Factory at IMMS, Wolfram Kattanek, offers support in the focus areas of intelligent sensor and measurement systems, sensor-related AI-based signal processing, condition monitoring of machines and predictive maintenance. In doing so, he makes an important contribution to raising awareness of AI topics and to the transfer of knowledge from research to SMEs. In addition to practical AI-related demonstration and implementation projects, knowledge transfer also takes place through online events, such as lecture events on AI topics and the series of AI developer roundtables. At the latter, on every second Tuesday of the month, interested parties are invited to gain insights into the technical implementation of AI and to meet regional players to exchange experiences. Developers present



Energy management of machinery and production lines. The video (in German) of the demonstrator shows how the energy consumption of injection moulding machines can be recorded and controlled in such a way that peak loads are avoided.

Source: IMMS.

a concrete AI solution or an AI development project from different perspectives: e.g. algorithm and model development or software and hardware development. The start was made by the StadtLärm* project, in which IMMS, Fraunhofer IDMT, Software Service John and Bischoff Elektronik developed solutions for AI-based noise classification in urban environments.

Know-how transfer with newly launched formats

Videos of demonstrators

At the beginning of 2020, the event planning was up and running with the established Sensors 4.0 workshops and regulars' tables. It was thematically underpinned, scheduled and ready to reach a broad audience in presence. Due to the onset of the pandemic, new formats for virtual events had to be established and video contribu-

Retrofitting a drilling machine with sensors, network capability and local AI. The demonstrator video (in German) uses a drilling machine to show how existing equipment can be retrofitted with sensors and AI, for example to record tool wear during machining. Source: IMMS.

Retrofittable stock monitoring. The video (in German) of the demonstrator shows how fill levels, e.g. of bulk material or other material containers, can be automatically determined via ultrasonic sensors. Source: IMMS.

tions had to be produced in order to bring the demonstrators, which can otherwise be seen live, closer to the SMEs in a technical manner despite the institute doors being closed.

(Online) events

In 2020, most of the events took place virtually. With the 56 information talks, four regulars' tables, two lecture events and two talks, the Migration Model Factory at IMMS reached 588 interested parties from almost all industries in Thüringen.

The highlight in January was the lecture event "**Smart Manufacturing – Sensor Technology in Production**" at the host VACOM Vakuum Komponenten & Messtechnik GmbH in Großlöbichau with over 100 participants from an organisational association of Thuringian networks.

In the course of the Corona pandemic, 19 Thuringian industry networks and clusters have joined forces as a so-called **Cross-Cluster Initiative (CCIT)** in order to bundle and offer all necessary company-specific Corona information centrally via a platform. This information is presented on the joint website netzwerktimer-thueringen.de. In addition, other offers are available there, such as a general overview of events that the networks and clusters in Thüringen are currently preparing and coordinating. IMMS supports the initiative primarily as an M40 actor and as a founding member of ELMUG eG.

From this association, a seven-day virtual **CCIT event series** with various professional workshops and conferences was also organised in September. IMMS also presented new M40 project results on one day. In addition, demonstrators were presented to a wide audience with pre-recorded video contributions or live presentations.

Late in summer it was possible to finalise the series of events with the Mittelstandsvereinigung pro Südthüringen e.V. on a small scale with the third information day at the beginning of October and to hold intensive discussions in small groups, answer questions and, in some cases, take up new project suggestions.

IMMS events for SME 4.0: www.imms.de

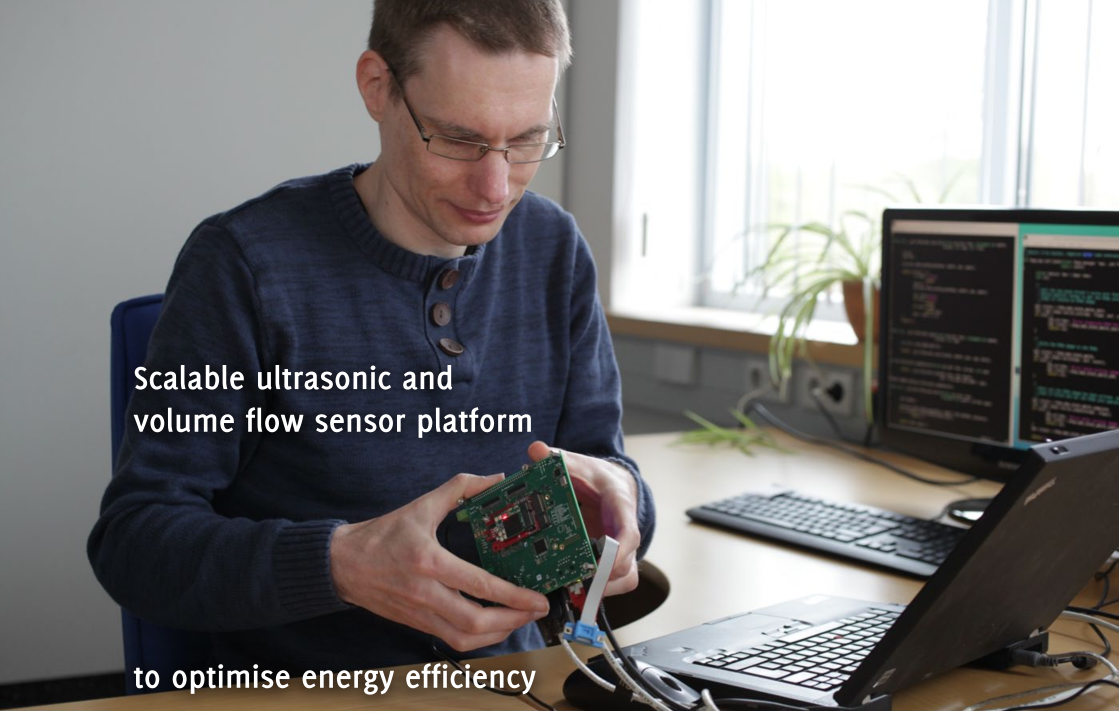
An outstanding event for the transfer work in M40 was the participation in the nationwide virtual **Digital Summit** at the end of November. The Competence Centre was represented with 5 contributions, 2 of which came from IMMS as the Migration Model Factory. Demonstrators and project results were presented in pre-produced video contributions. Questions could be answered in a subsequent live chat.

Another important event was **InnoCON**, the Thuringian RIS-3 annual event, where IMMS was represented together with all M40 model factories with a virtual 3D stand.

The remotely monitored public swimming pool – water disinfection with UV light. Video in German. Source: IMMS / Digital Summit 2020.

Energy-saving injection moulding through intelligent computer control. Video in German. Source: IMMS / Digital Summit 2020.

Scalable ultrasonic and volume flow sensor platform to optimise energy efficiency



Working on the electronics for an automatable sensor solution to use compressed air in industry in an energy-efficient way. Photograph: IMMS.

Motivation and overview

Compressed air leaks cause the most energy losses in industry. Up to 10% of electrical energy is used just to generate compressed air. 30% of this is lost on average due to leaks. Due to this it is very important to find leaks, evaluate losses and initiate maintenance measures. To use compressed air for industrial processes in an energy-efficient way, IMMS, together with the companies Sonotec GmbH and Postberg + Co. GmbH, has developed an automatable sensor solution for leakage detection and evaluation, with which compressed air systems can be retrofitted. This simplifies repair and maintenance decisions and significantly increases energy efficiency. The product will be launched on the market by Sonotec GmbH in 2022.

Functionality of the overall system

More on sUSe auf www.imms.de

The sUSe platform is an integrated monitoring system consisting of multiple, distributed, connected and permanently installed ultrasonic and volume flow sensors, which can be used to monitor and evaluate the energy efficiency of the compressed air systems (Figure 1). On the one hand, the volume flow, i.e. the integral quantity

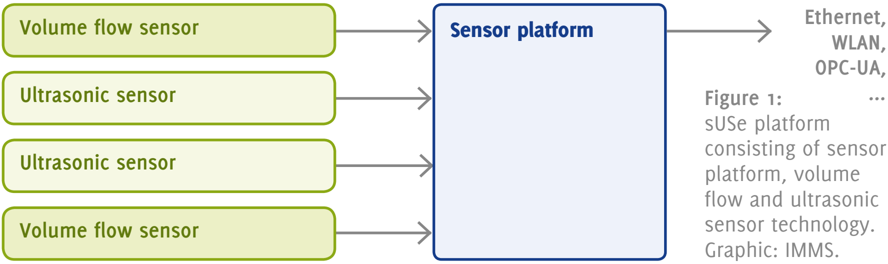


Figure 1: sUSe platform consisting of sensor platform, volume flow and ultrasonic sensor technology. Graphic: IMMS.

of compressed air, is measured with corresponding sensors at various points in the system and related to the quantity fed into the compressed air system. On the other hand, leaks are acoustically located and evaluated by the ultrasonic sensors. They are also distributed in the compressed air system and according to the relative arrangement to each other it is possible to locate the leak. From the combined data of total volume flow and identified leakage points, the proportions of leakage on the losses of compressed air can be determined precisely.

IMMS contribution: Electronics platform, signal processing and communications

IMMS has developed a high-performance and scalable electronics platform for the digital processing of sensor data.

In order to be able to precisely allocate shares of leakage points in the compressed air loss, the data of total volume flow and many ultrasonic sensors distributed over the system must be combined. Since the compressed air for many applications, such as for various actions of an industrial robot, is supplied at changing points in different quantities, the sUSe platform and all associated sensors must operate time-synchronously. Therefore, IMMS took a modular approach in designing the hardware components and connected the sensors using programmable logic devices (FPGA) to ensure the real-time capability of the system.

This edge platform for decentralised data processing is used for each measurement point of the monitoring system. To be able to adapt the sensors very flexibly for customer-specific tasks without a need for hardware changes, IMMS developed the components for signal processing using a model-based design technology and implemented the application algorithms for FPGA integration on this basis. For an integration into maintenance systems, suitable communications interfaces and protocols were implemented and the corresponding communications capability of the wireless sensors was established.

› Integrated sensor systems
› Distributed measurement + test systems
› Mag6D nm direct drives
› Contents
* Funding

The platform consists of a mainboard with integrated central processing unit (CPU), an FPGA and attachable sub-modules. In addition to the ultrasonic and volume flow sensors developed by the project partners, it should also be possible to integrate other commercially available sensors, such as pressure, temperature and acceleration sensors. To this end, preliminary investigations have been carried out and the transmission protocols and interfaces for integrating the sensors have been specified.

Mainboard

IMMS has investigated and compared available CPU modules for the mainboard. To minimise development effort and hardware costs, a Phycore iMx8M SoM (system on module) from Phytec was selected. It contains an iMx8 CPU, memory (LPDDR4 Ram and EMMC) and can optionally be equipped with a wireless module (WLAN, Bluetooth).

Another component of the mainboard is an FPGA, with which the interfaces to the sub-modules can be adapted to the specific application. The acquired signals from the sensors are further processed in the FPGA. Thus, level calculations, FFT and data compression can be performed. The data is then transferred to the CPU via a PCIe connection.

Furthermore, an M.2 connector has been applied to the board, which can be used to expand the system with additional components, such as the AI hardware accelerator "Google Coral AI Accelerator".

Services for embedded systems at www.imms.de

Sub-Basic

The base module is plugged onto the main board to implement power supply, communications interfaces (Ethernet, USB 3.0, RS485(Modbus)) and digital IO.

The power supply was designed for an input voltage range of 7 to 36 V. A circuit protects the downstream electronics from overvoltage, overcurrent and against reverse polarity of the supply voltage. The 5V system voltage generated in this way is then fed to the mainboard via a connector.

As communications interfaces, the Ethernet and USB 3.0 signals of the System-on-Module were routed to corresponding connectors. Furthermore, two galvanically isolated RS485 transceivers were integrated. Thus Modbus communications can be implemented.

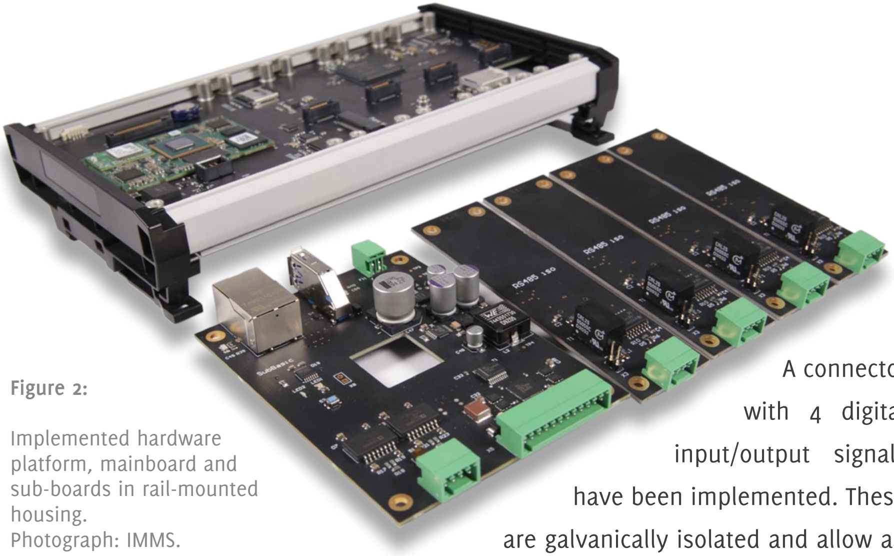


Figure 2:

Implemented hardware platform, mainboard and sub-boards in rail-mounted housing.
Photograph: IMMS.

A connector with 4 digital input/output signals have been implemented. These are galvanically isolated and allow an integration into existing systems.

Sub-communications modules

As the first communications modules, an RS485 and an LVDS module were designed to connect all sensors developed and used in the project to the platform. To increase noise immunity, communications and voltage supply of the sensors are galvanically isolated.

FPGA

With the FPGA the interfaces to the sensors are realized, the sensor data are preprocessed by FFT and level calculation and the data are buffered and forwarded to the CPU. The FPGA firmware can be adapted according to the application and the modules used.

FPGA and CPU communicate via a PCIe connection. Data is written to a buffer in the FPGA and then transferred to the CPU's memory using Direct Memory Access (DMA). Several available PCIe IP cores were evaluated and the XDMA subsystem for PCIe was implemented.

Sensor technology

The concept allows a number of sensor types to be connected, which can be used separately or in parallel (e.g. for real-time correlation) or towards data fusion. Digital sensors are ideal for the concept.

Board Support Package (BSP)

Based on the existing Board Support Package for the Phycore iMx8M SoM module, an appropriate adapted version was created that contains all software components required for the sensor platform. The Yocto distribution builder is used to create the BSP. Yocto is a framework that allows extremely flexible (Linux) distributions to be created from the source code of all the contained components. The information needed for this is organised in layers in the Yocto framework. This permits a fine grained control to adjust the created distribution to the necessary requirements. Accordingly, a sUSe layer was added to the existing layers. This layer contains the SOM configuration, presets for various software packages, build instructions for software not yet included in the other layers, etc.

In addition, support for the RAUC project (Robust Auto-Update Controller) has been added via another Yocto layer. With the help of the RAUC project, system updates can be performed in a very flexible, robust and tamper-proof way. For the sensor platform, RAUC has been configured so that a complete system update can be performed at runtime via redundant bootloader and rootfs partitions. This process is secured using digital signatures. Furthermore, it is also possible to perform the initial installation of the system software via the RAUC update mechanism. In addition, thanks to integration in the Yocto build process, RAUC update files are generated automatically.

Driver

For the data exchange between CPU and FPGA via PCIe, different drivers are necessary, which put into practice the different levels of interface communications. On the one hand there is a driver for the PCI host controller used in the SoC, which is already available in the Linux kernel. On the other hand a driver which controls the data exchange with DMA as well as its synchronization is required. An official driver for this purpose is provided by the manufacturer for the FPGA PCIe core.

However, various tests and research have shown that this driver does not allow reliable data exchange, especially on architectures other than i686. Therefore, IMMS has modified a community project, which provides a derived driver, and integrated it into the BSP. In addition, test programs have been created that allow recording data supplied by the FPGA via the PCIe interface.

Outlook

The Edge platform was primarily developed to optimise energy efficiency in compressed air systems. Here, the sensor platform can be used as a retrofit solution to permanently monitor the compressed air at industrial plant and machine parts, improve energy efficiency and thus contribute to reducing CO_2 emissions. However, the modular approach of the platform also makes it easy to use in other application scenarios, such as predictive maintenance.

In the next step, the system will be integrated and evaluated in industrial machinery and the use of the platform in other application fields will be demonstrated. The product will be launched on the market by Sonotec GmbH in 2022.

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Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

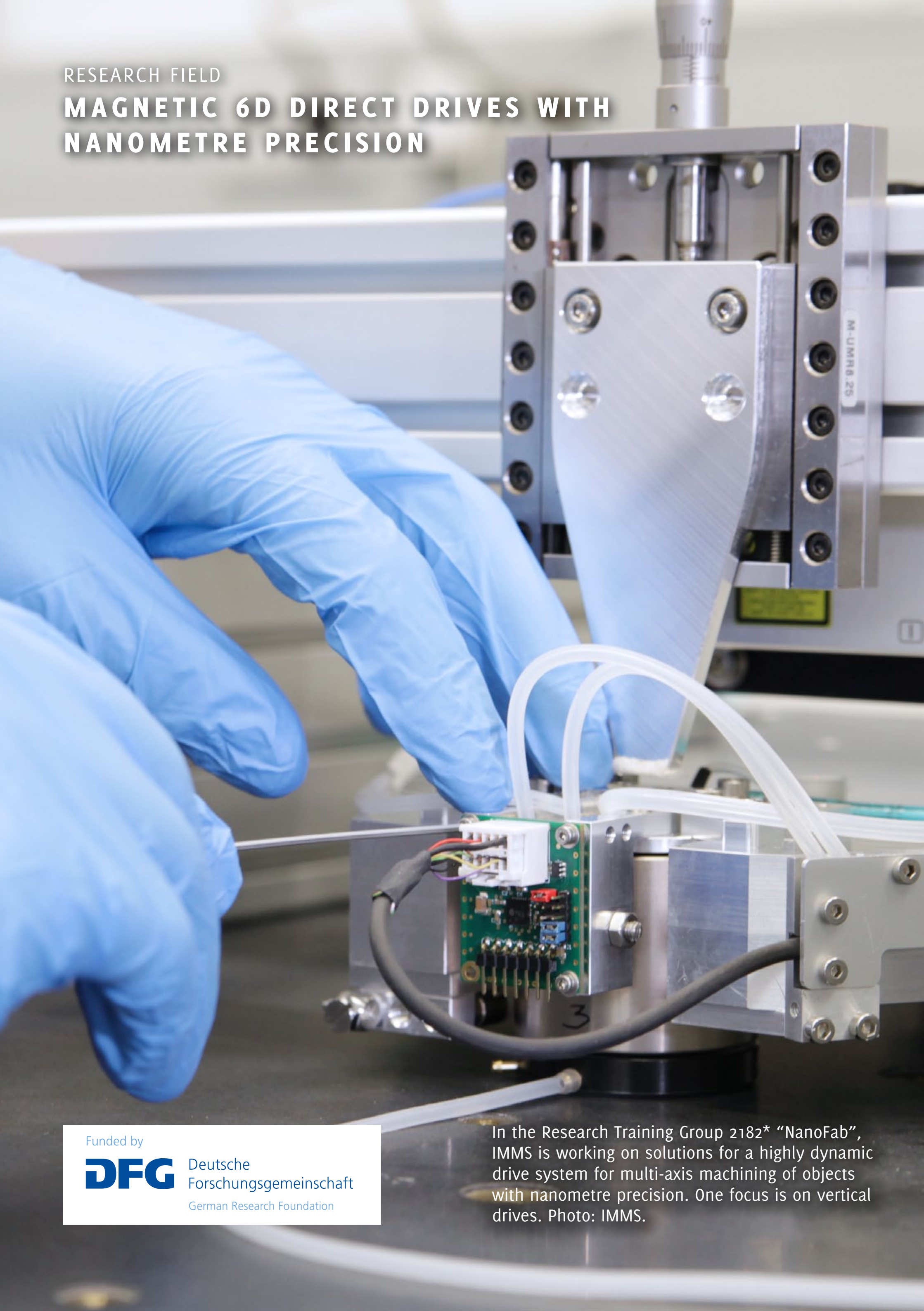
The sUSe project was funded by the Federal Ministry for Economic Affairs and Energy on the basis of a resolution of the German Bundestag under the reference ZF4085709P08.

Services for embedded systems at www.imms.de

More on sUSe auf www.imms.de

RESEARCH FIELD

MAGNETIC 6D DIRECT DRIVES WITH NANOMETRE PRECISION



In the Research Training Group 2182* “NanoFab”, IMMS is working on solutions for a highly dynamic drive system for multi-axis machining of objects with nanometre precision. One focus is on vertical drives. Photo: IMMS.

Funded by
DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Research field

Magnetic 6D direct drives with nanometre precision

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

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

Projects for direct drives www.imms.de.

Highlights of 2020 in our research on Magnetic 6D direct drives with nanometre precision

IMMS PhD student defends doctorate in the DFG Research Training Group NanoFab*.

Stephan Gorges, researcher at IMMS and member of the German Research Foundation (DFG) funded Research Training Group 2182 “Cutting-edge and laser-based 3D nanofabrication in extended macroscopic workspaces” (NanoFab) successfully defended his PhD thesis “A Lifting and Actuating Unit for a Planar Nanoprecision Drive System” at Ilmenau TU on 18 June 2020.

More on NanoFab at www.imms.de.

Vertical drive for 3D nanomanufacturing

“Many technical systems are becoming more and more miniaturised. The products themselves are still a few millimetres to centimetres in size. But surfaces and func-

Funded by DFG Deutsche Forschungsgemeinschaft German Research Foundation

Stephan Gorges on 18 June 2020 defending his doctorate on a vertical drive for for 3D nanomanufacturing, which he worked on in the Research Training Group 2182 (NanoFab).

Photograph: IMMS.

tional elements have to be structured and positioned with nanometre precision in the production process. This requires ever more precise precision machines," Stephan Gorges explained. It is already possible to structure below 10 nanometres in production – but only relatively slowly, with limited precision, without error corrections in the running process and, above all, only in small processing areas of a few 100 square micrometres.

But according to Gorges, it is not only larger working areas in a plane that are essential for perspective industrial suitability: "Vertical movements are a particular challenge. Because the gravity of the moving object must be permanently compensated." In his dissertation, he researched and developed a vertical lifting and drive unit that includes an electromagnetic precision drive and pneumatic weight force compensation. It can be integrated into overall systems and takes application-relevant criteria into account.

Research Training Group on 3D Nanofabrication in Macroscopic Working Areas

To be able to manufacture 3D freeforms on a large scale with nanometre precision and error correction, a total of 13 doctoral students have been conducting research in the NanoFab Research Training Group since April 2017 and have been supervised by professors and scientific staff at Ilmenau TU and IMMS. They are working on various method- and object-oriented topics at the levels of theory and metrology, tools and parallelisation, and kinematics and controls, including lithography, optical microsystems, real-time control and multidimensional force position control.

› *Integrated sensor systems*
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› *Mag6D nm direct drives*
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* *Funding*

From science to industry

“The parallel kinematic approach presented is not only characterised by its good integrability, minimal negative influences on the surrounding systems and the distribution of the load over several actuators,” is the assessment of Prof. Eberhard Manske, head of the Department of Manufacturing and Precision Metrology at Ilmenau TU and head of the Research Training Group. Vertical drives are also another milestone in the almost 25-year collaboration with IMMS, which makes an extremely valuable contribution to the TU’s research work through its expertise in the field of precision drive systems. “ IMMS is an important partner for TU in transferring nanopositioning and nanometrology into industrial applications,” Manske explained. For example, planar precision drives from IMMS have been incorporated into systems used worldwide in semiconductor manufacturing to separate thin 300 mm semiconductor wafers into microelectronics chips with high precision using laser dicing.

“The demands from industry are moving towards ever more precise systems. We are already talking about picometres. At the same time, however, ever larger stroke movements are to be carried out in production. In order to reconcile this, we need the research cooperation with the TU,” explained Dr Christoph Schäffel, Head of the Mechatronics Department at IMMS, who, along with Prof René Theska and Prof Bernd Hans Schmidt, was a supervisor for the doctorate and who had supervised Stephan Gorges at IMMS. “High-precision drives for new applications are a strategically important topic at IMMS. We are permanently working on this,” Schäffel continues. For example, work is being done on low-stray field planar motor structures, the scaling of travel ranges and novel solution approaches for the control and regulation of such drives.

More on NanoFab at www.imms.de.

Ready for take-off

The vertical drive developed was set up in the IMMS laboratory in 2020. For Stephan Gorges, things continued seamlessly at IMMS. He is involved in the K4PNP+Z* project, which started in 2020, to scale the lifting and drive unit to a larger positioning path and adapt it to a new application. Working with colleagues who, according to the German Research Foundation, are helping to define the worldwide state of the art in nanopositioning and nanometrology is a strong incentive for him, he says. “It’s great that we can make the technology so precise and, in this case, literally fly. That’s what everyone here is working hard for, and at the same time we are on equal footing. We help each other and learn a lot from each other – I would like to pass that on now.“

Project start of K4PNP+Z* – nanometre-precise drives with 25 mm vertical stroke

In the K4PNP-Z project, which started in 2020, IMMS develops actuators to position objects in planes with diameters up to 200 mm and a vertical stroke of 25 mm with nanometre precision.

K4PNP+Z at www.imms.de

Direct drives position wafers and exposure masks in semiconductor production with high precision within one plane. To enable objects to be lifted with nanometer precision over an area of more than only a few square millimeters, IMMS had already developed a 6D direct drive with partners. This can raise and lower objects through 10 mm under active control with nanometre precision in a travel range of 100 mm diameter in the plane.

Larger vertical movements limit precision and movement dynamics up to now

The requirements from industry do not only concern horizontal movements (x,y), in order to be able to structure and position surfaces and structures of millimetre

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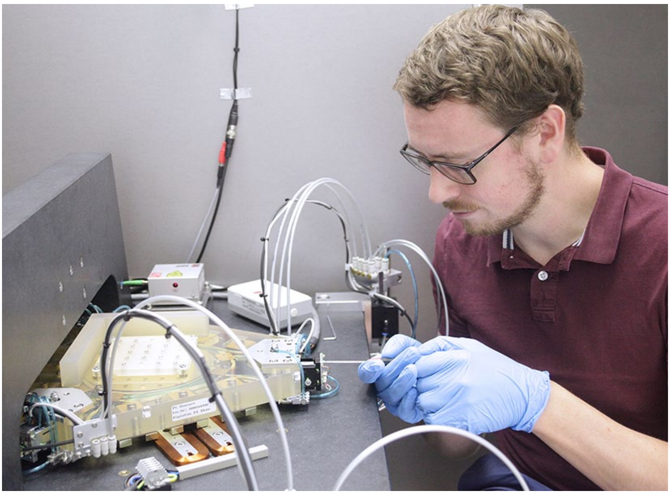
ZIM Zentrales Innovationsprogramm Mittelstand



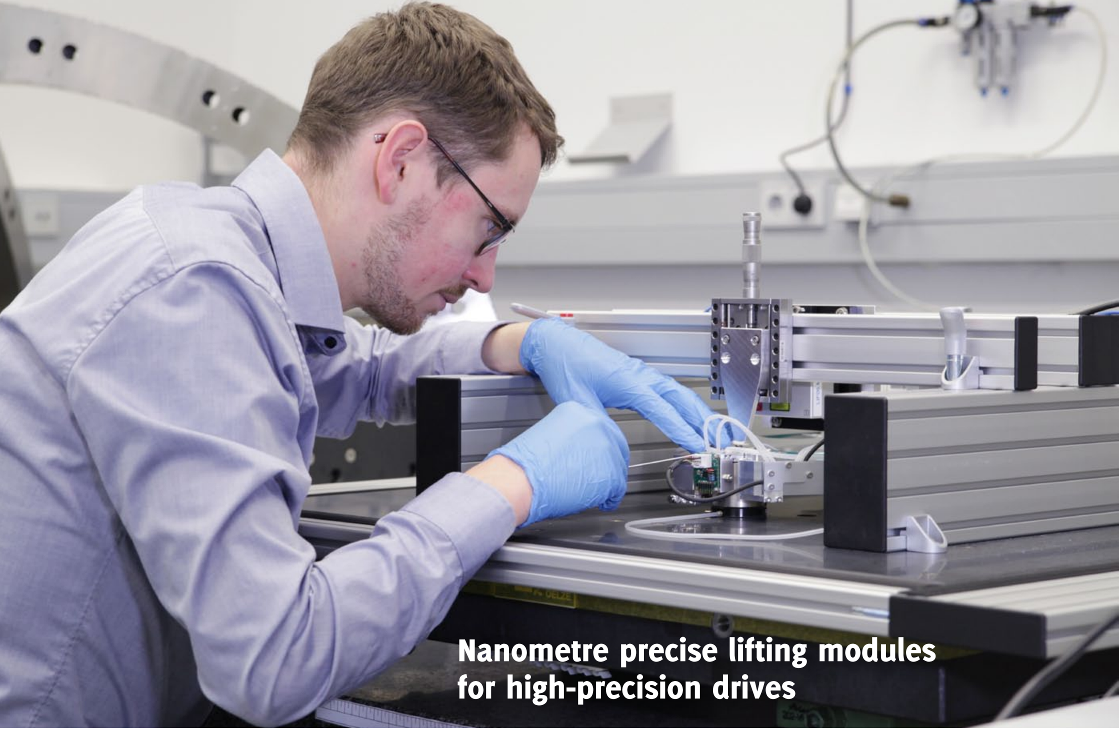
IMMS develops actuators to position objects in planes with diameters up to 200 mm and a vertical stroke of 25 mm with nanometre precision. Photo: IMMS.

or centimetre sized products with nanometre precision. Increasingly large vertical movements are to be carried out at the same time. The 6D direct drive works with electromagnetic vertical drives (z). The higher objects are lifted with it, the greater is the distance between the x-y drive coils, which are fixed to the frame, and the magnetic coils in the slider, which are required for the horizontal precision movements. Even a small amount of lifting drastically reduces the efficiency of the x-y drive system, multiplying power losses and thereby limiting the achievable motion dynamics due to thermal effects.

New vertical tracking elements will increase stroke distance

To overcome these hurdles, IMMS is working on concepts for new components in the K4PNP+Z project, with which the x-y drive coils, which have been fixed to the frame up to now, are now to be vertically tracked for a larger stroke and thus kept close to the magnets in the slider. These vertical tracking elements will be built, integrated into the overall system and experimentally investigated. Likewise, the vertical drive units for the higher travel distances and for higher payloads will be designed and tested. In perspective, z-strokes up to 25 mm with lateral travel ranges (x-y) over diameters of 200 mm are to be reached.

K4PNP+Z at www.imms.de



Nanometre precise lifting modules for high-precision drives

The lifting modules developed at IMMS operate in a travel range of 10 mm with an accuracy of up to 0.29 nm (standard deviation) and are optimised for use in manufacturing and metrology with an average heat dissipation of 54 nW. Photo: IMMS.

Motivation and overview

Positioning systems in semiconductor manufacturing and high-precision metrology need to move with increasing precision to cope with advancing miniaturisation. Increasingly larger vertical positioning ranges are required for new manufacturing processes. Therefore, IMMS has already developed a 6D direct drive that positions objects freely in space with nanometre precision in a planar range of ⌀100 mm and a lifting range of 10 mm. The newly improved lifting modules optimise the system for the use in manufacturing and metrology, thanks to their 75 % lower heat output. The developed design flow for large travel ranges is the basis for even more efficient and application-specific designs.

The basis for the redesign

Together with its partners, IMMS develops and implements precision drives for nanometre-precise positioning in travel ranges of 100 mm and more. By integrating

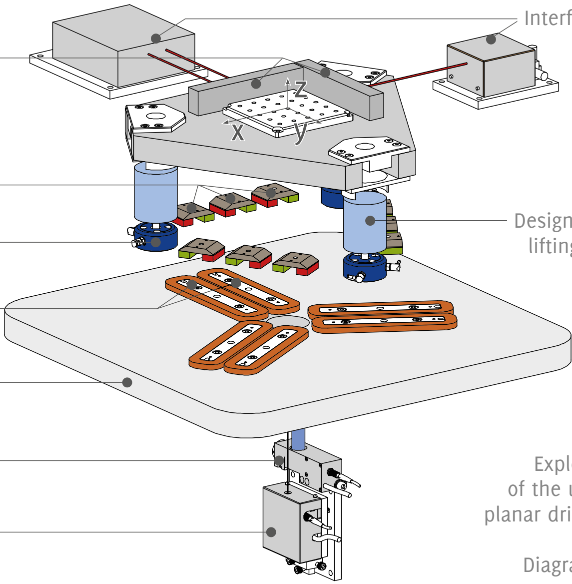


Figure 1:

Exploded view of the underlying planar drive system

Diagram: IMMS.

in-house developed lifting modules, not only planar positioning in the xy-plane is possible but also movement in the z-direction, for example over 10 mm.[1]

A newly developed design process is the basis for the optimised enhancement of these highly integrated lifting modules, enabling efficient and rapid design for future lifting-load combinations. For the redesign of the lifting modules, the underlying planar drive system (Figure 1) was considered holistically. It is based on a monolithic central body (slider), which sits on three air bearings allowing a frictionless motion in the xy-plane.

Utilizing 4 laser interferometers, an autocollimator and plane mirrors integrated into the slider, it is possible to determine its position and orientation in space. Fixed coils generate forces on NdFeB magnets on the underside of the slider, allowing it to be moved precisely in the x- and y-directions. Additional guidings and actuators are introduced between the air bearings and the corners of the central body to allow a 10 mm z-stroke of the slider and to eliminate the remaining errors in the tilt angles φ_x and φ_y. With this arrangement, only minimal modifications of the slider are necessary and it is possible to use 3 identical modules on which the sliders mass of approx. 12 kg is evenly distributed.

1 *https://www.ingenieur.de/fachmedien/konstruktion/antriebstechnik/hochpraezise-positionieren/*

Physical effects that are negligible in classical mechanical engineering can have a considerable influence on the achievable accuracy in precision metrology. In order to meet all requirements, a suitable constructive development process is essential. Here, the design principles from precision engineering (separation of functions) are harmonised with those from mechatronics (integration of functions). This applies in particular to the two functional core components: the vertical drive and the vertical guide.

The new lifting module should be capable to lift 4 kg over 10 mm with nanometre accuracy and stick-slip-free. The available design space is only about ⌀ 50 mm x 60 mm. Special emphasis is put on the generated heat during operation: It should be minimised, since any heating results in thermal expansion and thus loss of precision. In addition, the drive and guide should be designed in such a way that they can be easily scaled up for larger loads and travel ranges. An analysis of suitable drive principles (pneumatic, piezoelectric, electromagnetic) has shown that none alone meets all requirements adequately.

A modification of the coarse drive/fine drive principle yields a suitable solution: A first actuator significantly compensates the weight force, thus a second actuator only needs to create very small forces to enable precision positioning. A pneumatic cylinder is especially suitable as a weight force compensation, as it has a high force density, does not locally introduce heat into the system and can be adjusted to different loads via the pressure. A pneumatic cylinder is particularly suitable for weight force compensation, as it has a high force density, does not introduce any heat into the system locally and can be adapted to different loads via the pressure. The remaining low but highly dynamic precision forces can then be achieved by an optimally shaped electromagnetic actuator. Furthermore, both actuator principles can be adapted very well to larger strokes and loads.

Aerostatic guidings are especially suitable as a frictionless guiding system. They can be integrated very well into the pneumatic cylinder without compromising on functionality.

Modelling the actuators is the central step in the design process. With the help of these models, conclusions can be drawn about the static and dynamic behaviour as well as the air consumption of the pneumatic cylinder. Thus, the piston-cylinder combination with a frictionless seal was ideally adapted to the requirements and the existing infrastructure.

The design of the electromagnetic actuator has a significantly higher degree of freedom and is thus the key to application-specific designs: A wide variety of magnet arrangements can be combined with differently designed iron yokes and coils. Using a universal performance parameter, 13 topologies were investigated to find the ideal drive for the given boundary conditions. For precision drives the force-to-power ratio is particularly suitable, since the drive structures can be evaluated independently of the used power amplifier and the expected trajectory curve.

The electromagnetic field simulations are embedded in a numerical optimisation to find the ideal geometry for each topology. The derived electromagnetic drive has a force-to-power ratio of over 60N²/W while fitting in a space of approx. ⌀ 50 mm x 40 mm. In Figure 2 the corresponding optimisation run (left) and the magnetic field distribution (right) can be seen.

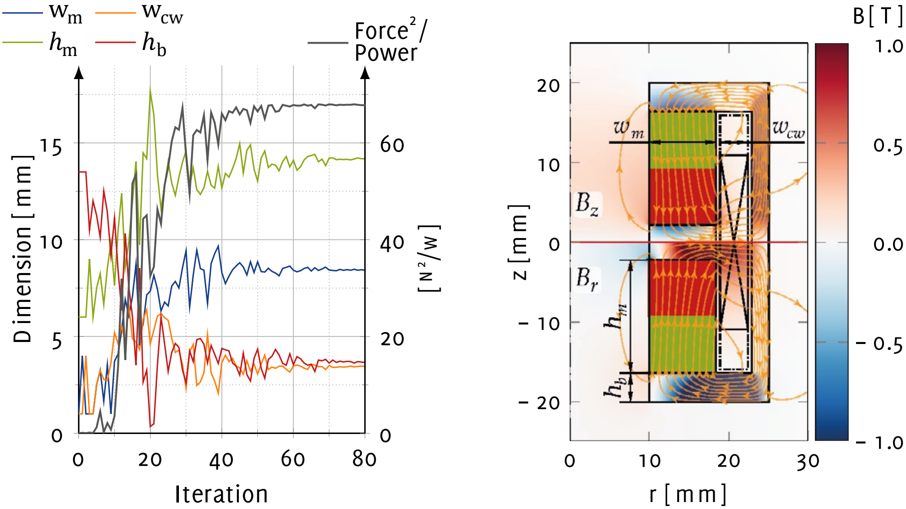


Figure 2: left: Optimisation of the actuator geometry for the chosen drive topology found via an automised optimisation algorithm which derives the dimensions of the magnet and coil (w_m, w_{cw}, h_m, h_b); **right:** 2D-cross section of the optimal drive geometry, its FEM results and magnetic flux density. Diagrams: IMMS.

The final geometry of magnet, coil and yoke yield an electrodynamic actuator with maximum force-to-power ratio and a homogeneous distributed flux density along the stroke of the coil, see Figure 2 right. Thus, the drive force characteristics are close to constant along the travel. From a subsequent parameter study a coil can be chosen which fits best to the used power amplifier. Overall, the dissipated heat of the drive has been reduced by approx. 75% compared to the previous lifting module. If needed, the remaining low power losses can be discharged from the measuring chamber via an integrated cooling system.

Additionally to the design results above, a proven design procedure is now available. In the future it can be used to quickly and efficiently derive new lifting modules for other travel, load and design space requirements.

Results pave the way for industrial application

Figure 3 shows the derived lifting module. The electromagnetic drive encloses most of the other components, therefore all driving forces act exactly along the guiding axis. Thus, parasitic tilting loads can be avoided. Disturbing forces created by the drag of the tubes and wires were greatly reduced by integrating all those components that require a supply line into the slider-fixed assembly.

Figure 4 shows the first measurement results from a single axis measuring stand, which confirm the simulations. At first, the module was set down and resting on the massive granite stator. The noise in the position signal has a standard deviation of 0.22 nm; hence it represents the theoretical limit. In closed-loop operation (aerostatic guiding, pneumatic weight-force compensation, magnetic drive and ac-

Figure 3:

Newly developed lifting module.

Photograph: IMMS.

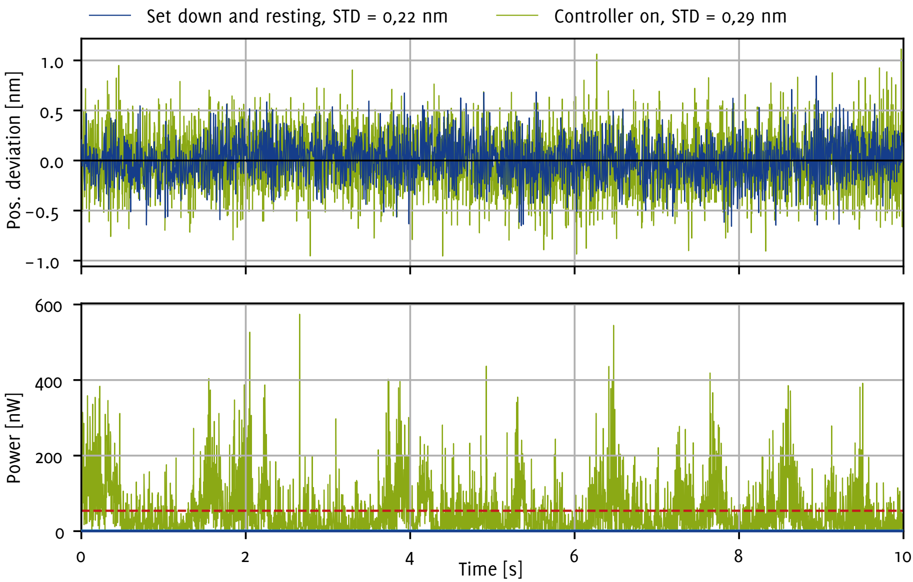


Figure 4: top: the blue graph represents the position measurement while the module was unpowered and resting on the base, the green graph shows the position deviation from the setpoint in closed-loop operation (with active pneumatic weight-force compensation and position control via the electromagnetic drive); **bottom**: the corresponding electrical power for the positioning process (red: green: in the magnetic drive, average power of 54 nW). Diagrams: IMMS.

tive controller) the standard deviation grew only marginally to 0.29 nm, while the extremely low average electrical power of just 54 nW was achieved.

The newly developed lifting modules have proven that it is possible to lift several kilogrammes through a macroscopic travel range with nanometre precision, while only emitting some nanowatts of heat into the measurement space. Thus, they mark an important milestone for the industrial application in 6D-measurement and nanofabrication systems, which move objects on complex spatial trajectories with subnanometre precision. Moreover, the developed constructive design process is currently proving its effectiveness in the development of new modules for a lifting range of 25 mm and a load of 13 kg.

Services for mechatronic systems at www.imms.de

Contact person: Dr.-Ing. Stephan Gorges, stephan.gorges@imms.de

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DFG Deutsche Forschungsgemeinschaft
German Research Foundation

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More on NanoFab at www.imms.de.

This text is based on the results of the dissertation "A lifting and actuating unit for a planar nanoprecision drive system", by Stephan Gorges (https://www.db-thueringen.de/receive/dbt_mods_00047399)

PROOF
THROUGH FACTS AND FIGURES

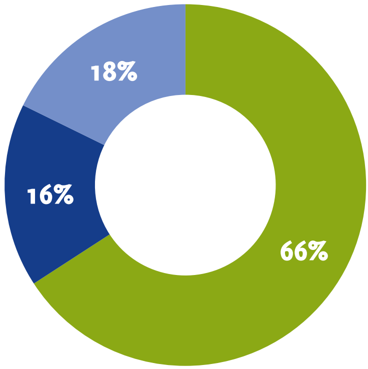
Preparations for measurements of the smallest semiconductor structures at wafer level in the cleanroom metrology laboratory. Photograph: IMMS.

Facts and Figures in 2020

At the end of the 2020 financial year, 79 people were employed at IMMS.[1] Of these, 52 scientists and 14 students worked in research and development. This corresponds to around 84 % of all **employees**. 12 employees and one apprentice supported them in administration.

As part of the training in practice-oriented research, a total of 29 students were supervised at IMMS in the 2020 financial year, including 3 Bachelor's theses and 9 Master's theses, and 8 employees were enrolled for their doctorate at a university.

Staff structure



Scientists | administration/apprentice | students

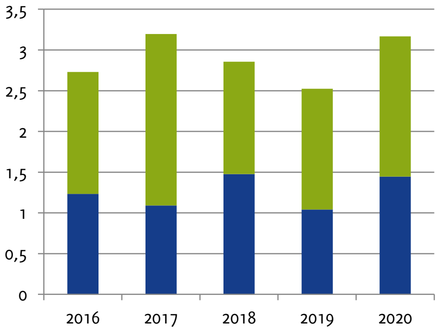
In 2020, we were able to attract new young scientists from international universities and industry to IMMS. The recruitment of further scientific staff is increasingly facing the challenge of declining numbers of graduates in the disciplines relevant to the Institute as well as the increasing competition for the best talents. Overall, a variety of nationalities were represented at IMMS in 2020, which strengthens the international exchange for research and development at IMMS.

Third-party funding earnings increased significantly in 2020, so that in a 5-year comparison it was possible to almost match the high level of 2017. This is reflected in particular in the development of earnings from industrial projects, which was above the previous year's level. Here, the market-driven high demand of our partners for industrial contract research with our future topics had a particular impact. Earnings from publicly funded research also increased compared to the previous year. The increase in publicly funded third-party earnings is partly due to the fact that the research topics worked on by IMMS are of high current relevance. The positive development of third-party funding is also reflected in the revenues, which were around 29 % higher than in the previous year. Both the revenues from industrial projects and from public funding projects could be increased.

1 *As the staffing figures given are actual numbers for 31.12.2020 without calculation of full-time equivalent, only limited comparison with those in earlier annual reports is possible.*

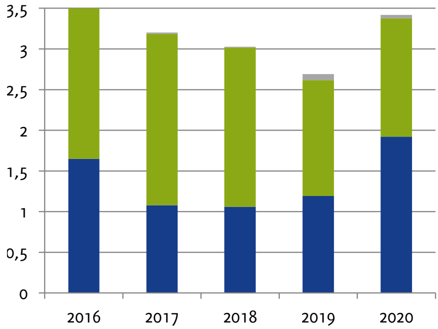
Project **earnings**

Industrial projects / funded projects
in million €



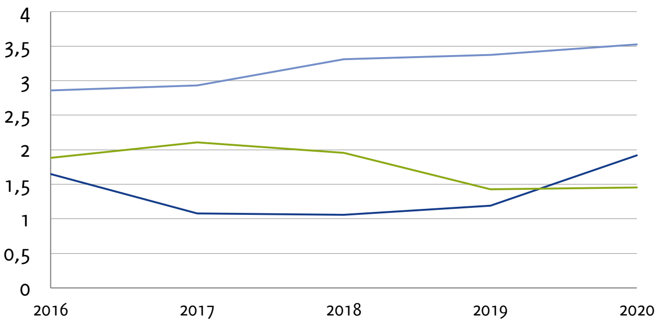
Project **revenues**

Industrial projects / funded projects / others
in million €



The **institutional funding** from the German Land of Thüringen serves to finance the scientific-technical infrastructure and the scientific-technical preliminary work as the basis for the Institute's innovative strength. In combination with the funds from publicly funded research projects and the turnover from industrial contract research, institutional funding continues to be of great importance for the financing of the research tasks and thus for the feasibility of the applied research of IMMS as a whole. It is the basis of the Institute's funding. In particular, the funding of the internal research groups makes it possible to work on research foci that are essential for strategic development, regardless of the availability of funding through public funding offers.

Pillars of financial support
in million €



Basic funding (institutional support)

Revenues from industry

Public project funding

More on funding at www.imms.de.

Organisation in 2020

Scientific Advisory Board

Supervisory Board (Chair: TMWWDG[1])

Proprietor German "Land" of Thüringen

Management Board

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Ralf Sommer, Univ.-Prof. Dr.-Ing.

Financial Managing Director
Martin Eberhardt, Dipl.-Kfm.

Administration Mario Görlach, Business economist (VWA)

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Microelectronics Eric Schäfer, M.Sc.

Mechatronics Christoph Schäffel, Dr.-Ing.

System Design Tino Hutschenreuther, Dr.-Ing.

Industrial Electronics and Measurement Technology Michael Meister, Dipl.-Ing.

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- Andreas Rohwer, Ministry of Finance Thüringen, Germany
- Univ. Prof. Dr.-Ing. habil. Kai-Uwe Sattler, President of Technische Universität Ilmenau
- Prof. Dr. rer. nat. Ingolf Voigt, Deputy Managing Director and Site Manager, Fraunhofer Institute for Ceramic Technologies and Systems IKTS, Hermsdorf
- Cathrin Wilhelm, Managing Director, BINZ Ambulance- und Umwelttechnik GmbH, Ilmenau

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- Prof. Dr. Ulf Schlichtmann, München University of Technology, Faculty of Electrical Engineering and Information Technology, Chair of Design Automation
- Prof. Dr. Ansgar Trächtler, Chair of Control Engineering and Mechatronics, University of Paderborn, Heinz Nixdorf Institute; Executive Director Research Division Scientific Automation, Fraunhofer Institute for Mechatronic Systems Design IEM
- Jörg Wende, Consultant Hybrid-Integration and Industry 4.0, IBM Deutschland GmbH, Dresden

Lectures, lecture series

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

- Grundlagen der analogen Schaltungstechnik, lecture and tutorial,
- Rechnergestützte Schaltungssimulation und deren Algorithmen (EDA), lecture and tutorial
- Modellierung und Simulation analoger Systeme, lecture and tutorial

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

- Theoretische Elektrotechnik I und II, lecture
- Schaltungen der Quanteninformationsverarbeitung, lecture
- Elektromagnetische Sensorik, lecture
- Technische Elektrodynamik, lecture
- Supraleitung in der Informationstechnik, lecture
- Project seminar ATET

Events

Workshops / IMMS as host, organiser or co-initiator

21 Jan 2020 – Industrieforum „Smarte Fertigung – Sensorik in der Produktion“, industry forum on smart manufacturing and sensors in production”, *organisation, lecture,* VACOM Vakuum Komponenten und Messtechnik GmbH, Großlöbichau

06 Feb 2020 – Informationstag Technikerklasse Berufsschule „Jakob-Preh“, information day technician class vocational school, *organisation, lecture, demonstrators,* event at IMMS Ilmenau

25 Feb 2020 – User Group Meeting – Fachgruppe KI, AI specialist group meeting, event at IMMS, Ilmenau

18 Feb 2020 – edaBarCamp -- Number 5 is alive, BarCamp on electronic design Automation, *organisation, workshop, lecture,* IBM Deutschland Research & Development, Böblingen

16 Sep 2020 – Cross-Cluster-Woche Thüringen „Virtuell vernetzen, regional kooperieren“, series of events of the Thuringian networks for vitual and regional cooperation, *Organisation, lecture, videos, live demonstrations,* online event

Current events: www.imms.de.

30 Sep 2020 – Mittelstandsvereinigung pro Südthüringen e.V., *organisation, lecture, live demonstration,* event of the Thuringian Association of Small and Medium-Sized Businesses, event at IMMS Ilmenau

13 Nov 2020 – Stammtisch Kollaboration, Regulars' table of the SME 4.0 Competence Centre Ilmenau, *organisation, lecture,* online

Conferences with contributions by IMMS

16 Feb 2020 – TuZ 2020, 32th GI/GMM/ITG workshop on test methods and reliability of circuits, *lecture,* Ludwigsburg near Stuttgart

19 Jun 2020 – Bundesweiter Digitaltag 2020, German-wide Digital Day, *lectures*, online

20 Jul 2020 – IEEE SSD 2020 (SCI) , International Conference on Sensors, Circuits and Instrumentation Systems 2020 at the 17th IEEE International Multi-Conference on Systems, Signals & Devices 2020, *lecture*, online

28 Sep 2020 – Analog 2020, 17th ITG/GMM symposium on analogue circuits as key systems for automotive, IoT and future wireless technology, *2 lectures*, online

02 Oct 2020 – TCoNS 2020, Workshop on Tools and Concepts for Communication and Networked Systems, *lecture*, Karlsruhe

11 Oct 2020 – ISCAS 2020, IEEE International Symposium on Circuits and Systems, *lecture*, online

13 oct 2020 – CadenceLIVE Europe 2020, conference on electronic design tools and methods, *lecture*, online

24 Nov 2020 – InnoCON Thüringen 2020, *virtual booth, lecture*, online

30 Nov 2020 – Digital-Gipfel 2020, *2 demonstrators, videos, live chat,* online

07 Dec 2020 – Thüringer KI-Forum, *panel discussion on AI,* online

08 Dec 2020 – SMEKUL-Werkstatt workshop on digitisation in fruit growing and viticulture, *lecture*, online

Current events: www.imms.de.

Video productions for demonstrators and for online events

- *Retrofitting a drilling machine with sensors, network capability and local AI*
- *Energy management of machinery and plant*
- *Retrofittable stock monitoring*
- *Energy-saving injection moulding through intelligent computer control*
- *The remotely monitored public swimming pool – water disinfection with UV light*
- *25 years of IMMS*

More Videos at www.imms.de

Reviewed Publications

Net-QoS – Adaptierung der Anwendungs-Quality-of-Service-Parameter an die Netzwerk-Quality-of-Service-Parameter, Björn Barig[1]. Thomas Elste[1]. Tino Hutschenreuther[1]. Rolf Peukert[1]. Sebastian Uziel[1]. *Forschungsbericht, Nr. 14/2020, Studie der Deutschen Gesellschaft für die Anwendung der Mikroelektronik e.V. (DFAM).* **www.dfam.de/service-studien-handbuecher.php.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany.

Light-Controlled Photometer with Optoelectronic CMOS Biochip for Quantitative PSA Detection, Alexander Hofmann[1]. Michael Meister[1]. Alexander Rolapp[1]. Peggy Reich[1]. Friedrich Scholz[2]. Eric Schäfer[1]. *2020 IEEE International Symposium on Circuits and Systems (ISCAS), Sevilla, 10 – 21 October 2020, pp. 1 – 5,* **DOI: doi.org/10.1109/ISCAS45731.2020.9180796.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, 98693 Ilmenau, Germany. [2]Senova Gesellschaft für Biowissenschaft und Technik mbH, Weimar, Germany.

NISP: An NFC to I^{2}C Sensing Platform with Supply Interference Reduction for Flexible RFID Sensor Applications, Jun Tan[1]. Muralikrishna Sathyamurthy[1]. Alexander Rolapp[1]. Jonathan Gamez[1]. Moataz Elkharashi[1]. Benjamin Saft[1]. Sylvo Jäger[2]. Ralf Sommer[1]. J. Tan et al. in *IEEE Journal of Radio Frequency Identification.* **DOI: doi.org/10.1109/JRFID.2020.2967862.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, 98693 Ilmenau, Germany. [2]Micro-Sensys GmbH, Erfurt, Germany.

Tip- and laser-based nanofabrication up to 100 mm with sub-nanometre precision, Ingo Ortlepp[1]. Michael Kühnel[1]. Martin Hofmann[1]. Laura Weidenfeller[1]. Johannes Kirchner[1]. Shraddha Supreeti[1]. Rostyslav Mastylo[1]. Mathias Holz[1]. Thomas Michels[1]. Roland Füßl[1]. Ivo W. Rangelow[1]. Thomas Fröhlich[1]. Denis Dontsov[2]. Christoph Schäffel[3]. Eberhard Manske[1]. *Proc. SPIE 11324, Novel Patterning Technologies for Semiconductors, MEMS/NEMS and MOEMS 2020, 113240A (23 March 2020),* **DOI: doi.org/10.1117/12.2551044.** [1]Technische Universität Ilmenau, Germany. [2]SIOS Meßtechnik GmbH, Germany. [3]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, 98693 Ilmenau, Germany.

Publications for other years: www.imms.de.

Herausforderungen beim Einsatz von Sensorik und Monitoringlösungen im Obst- und Weinbau, Silvia KRUG[1]. Rikard GRAß[2]. *SMEKUL-Werkstatt, Workshop "Innovative Ideen und Lösungen für den Obst- und Weinbau", 8. Dezember 2020, Meißen, hybrid.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, 98693 Ilmenau, Germany. [2]Helmholtz-Zentrum für Umweltforschung GmbH - UFZ, Department Monitoring- und Erkundungstechnologien.

„Kommunikation – verständlich, oder? – Werkzeuge zur Gestaltung der Kommunikation in KMU mit modernen Kollaborationstools", Franziska BUCHWALD[1]. *Stammtisch Kollaboration „Business Chats – Anwendungen und Stolpersteine", 13. November 2020, online.* 1IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, 98693 Ilmenau, Germany.

Power to the Model: Generating Energy-Aware Mixed-Signal Models using Machine Learning, Martin GRABMANN[1]. Frank FELDHOFF[2]. Georg GLÄSER[1]. *CadenceLIVE 2020 Europe, 13 – 14 October 2020.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ilmenau, Germany. [2]Ilmenau University of Technology, Ilmenau, Germany.

Evaluation of Interoperability Between Various Implementations of the Thread Protocol Stack, Sebastian MIETHE[1]. Silvia KRUG[1]. *Workshop on Tools and Concepts for Communication and Networked Systems (TCoNS), 2 October 2020, online.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, 98693 Ilmenau, Germany.

Ain't got time for this? Reducing manual evaluation effort with Machine Learning based Grouping of Analog Waveform Test Data, Tom REINHOLD[1]. Marco SEELAND[2]. Martin GRABMANN[1]. Christian PAINTZ[3]. Patrick MÄDER[2]. Georg GLÄSER[1]. *Analog 2020, 17. ITG/GMM-Fachtagung, Analoge Schaltungen: Schlüsselsysteme für Automotive, IoT und zukünftige drahtlose Technologien, 28 – 30 September 2020, online.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ilmenau, Germany. [2]Technische Universität Ilmenau, Ilmenau, Germany. [3]Melexis GmbH, Erfurt, Germany.

Publications for other years: www.imms.de.

Entwurf, Evaluierung und Optimierung von HF- und UHF-RFID-Sensorsystemen, Björn BIESKE[1]. Tom REINHOLD[1]. Jun TAN[1]. *Analog 2020, 17. ITG/GMM-Fachtagung, Analoge Schaltungen: Schlüsselsysteme für Automotive, IoT und zukünftige drahtlose Technologien, 28 – 30 September 2020, online.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, 98693 Ilmenau, Germany.

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Abbreviations

5G *Fifth generation mobile radio standard*

ADC *Analog-to-digital-converter*
AI *Artificial intelligence*
API *Application programming Interface*
ASIC *Application-specific integrated circuit*

BSP *Board support package*

CMOS *Complementary metal–oxide semiconductor*
CPU *central processing unit*

DMA *Direct memory access*

EDA *Electronic design automation,*

FEM *Finite element method*
FFT *Fast Fourier transform, an algorithm*
FPGA *Field programmable gate array*

I^2C *Inter-integrated circuit*
IC *Integrated circuit*
IEEE *Institute of Electrical and Electronics Engineers*
IO *Input/output*
IoT *Internet of things*
ISFET *Ion sensitive field effect transistor*

LFA *Lateral flow assay*
LH *luteinising hormone*

MEMS *Micro-electro-mechanical system*
ML *Machine learning*

NdFeB *Neodymium iron boron alloy for the strongest permanent magnets*

PCA *Principal component analysis,*
PCB *Printed circuit board,*
PCIe *Peripheral component interconnect express*
POCT *Point-of-care test system*

RFID *Radio-frequency identification*
RAUC *Robust auto-update controller*

S2DES *Smart sensor-based digital ecosystem services, cloud service of the S2DES project*
SAR *Successive approximation register*
SiCer *Silicon (Si) ceramic (Cer) composite substrate*
SME *Small and medium-sized enterprise*
SoM *System-on-module*
SPICE *Simulation software for electronic circuits*
SQUIDs *Superconductive quantum interference devices*

TDNN *Time delay neural network*

ULP *Ultra low power*

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