ANNUAL REPORT OF THE FRAUNHOFER-INSTITUTE FOR MICROELECTRONIC CIRCUITS AND SYSTEMS IMS DUISBURG 2010
The end of the global economic crisis led to a good operating result in the 26th year of Fraunhofer IMS. The Fraunhofer IMS operating budget in 2010 amounts to 20.8 million euros. In comparison to last year the number of employees slightly increased again.

The IMS used the challenging global economic situation in 2009 to concentrate on new strategic challenges and emerged from the crisis stronger than before. We could generate a series of public proceeds and gain also new, major industrial projects. The pick-up of the national and international markets allows for good future prospects for 2011.

**Project Highlights 2010**

A main focus of our work laid on IR-Imagers. The IMS developed an infrared-imager with VGA-resolution for the detection of thermal radiation for a wavelength range of 8 µm to 14 µm. A part of the required process steps for the IR-Imager will be performed in the 2011 new opened MST-Lab.

In the field of high temperature electronics we develop in cooperation with a project partner modern ASICs which are applicable for operating temperatures up to 250°C. Since several years, high temperature electronics have been one of the strategic fields of activity of Fraunhofer IMS.

In 2010, the Fraunhofer IMS processed, for our long lasting partner Infineon, SOI-Wafer, whose ICs are applied in power switches. This successful cooperation will be also an important pillar for us in 2011.

In a common international project inside the “HTA”, an association of the Fraunhofer Group of Microelectronics, Leti (FR), CSEM (CH) and VTT (FIN), high voltage transistors for a 0, 25 µm process are developed.
Events 2010

In 2010, a multitude of events and workshops have been performed at Fraunhofer IMS and at Fraunhofer InHaus Center. In March 2010, the GMM-Workshop “Reliability of semiconductor devices”, carried out at the Fraunhofer Inhaus Center, attracted numerous experts to come to Duisburg. National and international experts discussed the opportunities and methods to design devices, which also fulfill the strict medical and industrial requirements in future. Continuative discussions and network contacts resulted from the attractive supporting program.

Our 5th CMOS Imaging Workshop in May 2010 attracted again more than hundred national and international guests and orators. In accordance with the global technological trend, the topic of the workshop was “CMOS Low-Light-Imaging”.

The Win² event in June and the inHaus forum in September 2010 dealt both with the topic “buildings of the future”. The events focused on solutions for the technical modernization and the use of sensor technologies for the building services engineering.

From the 4th to 6th November, more than 30 pupils participated at the Fraunhofer Talent School in our institute. The Fraunhofer Talent School offers young, talented pupils the possibility to deal practically with scientific-technical topics. The participants set up radio circuits, learned about microchip design and simulated and designed microchips at the computer.

The Fraunhofer IMS was co-organizer of the workshop for “Energy self-sufficient sensors and sensor networks” of the Fraunhofer Gesellschaft in Munich. There, ten Fraunhofer Institutes presented their current trends and developments.

Personnel

In 2010, three Fraunhofer IMS employees were offered a professorship. We are happy about the career advancement of Professor Dr. Stockmanns, Professor Dr. Krisch and Professor Dr. Ressel and wish them success in following their new responsibilities. This pleasant progress verifies the academic esteem of the German universities.

For the overall excellent business year 2010, thanks are due to our partners and customers in commerce and the public authorities as well as in the ministries. In this context, the rise in orders coming from our European neighbors is especially pleasant.

Finally, I particularly would like to thank our employees, who enabled our common success by their dedicated work. Many thanks.

Professor Dr. rer. nat. Anton Grabmaier

Duisburg, March 2011
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- CMOS-based EUV sensor
  
  F. Hochschulz, U. Paschen, H. Vogt

- Thermally isolated mono-crystalline silicon diodes as detectors for microbolometers
  
  P. Kropelnicki

#### II  Silicon Sensors and Microsystems

- Post-CMOS MEMS integration based on novel approach with Ge micromechanics
  
  Q. Wang, A. Goehlich, H.-K.Trieu

- UniHealth – Universal sensor system for the detection of allergens and biomarkers
  
  C. Jonville, R. Klieber, A. Goehlich, H.-K. Trieu

- Building the future of CMOS imagers
  
  J. Fink, W. Brockherde
III CMOS Circuits

An 868 MHz Passive Temperature Sensing Transponder Using a Self-Biasing UHF Rectifier with –10.5 dBm Sensitivity in Low-Cost 0.35 µm CMOS
T. Feldengut, S. Kolnsberg, R. Kokozinski

On Chip Digital Readout Electronics for Large Scale IR Image Sensors
R. Lerch

IV Wireless Chips and Systems

»SmartForest – Application of Transponder Technology and Wireless Sensor Networks in Forestry«
H.-C. Müller

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Crash Sensor Systems for High-bay-racks
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MeDiNa – Telemedicine rehabilitation support in one’s own four walls
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V Systems and Applications

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O. Lazar

JUTTA – Care According to Individual Needs
T. Stevens
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- inHaus-center events 2010  
  B. Tenbosch, K. Scherer  
- Workshop on energy self-sufficient sensor networks  
  C. Müller  
- News from trade fair VISION 2010 and ELECTRONICA 2010  
  S. van Kempen, M. van Ackeren  
- The Fraunhofer-Talent-School  
  S. van Kempen, K. Althammer  
- Workshop: Reliability of Semiconductor Devices  
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The Fraunhofer Institute for Microelectronic Circuits and Systems (IMS) was established in Duisburg in 1984. The Fraunhofer IMS is, through continued growth and innovative research and development, one of the leading institutes in Germany for applied research and development in microelectronics and CMOS-technology.

**Fraunhofer IMS**

<table>
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<th>Employees</th>
<th>260</th>
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<tr>
<td>Budget</td>
<td>18.5 Mio. Euro</td>
</tr>
<tr>
<td>Industrial Projects</td>
<td>50 % of Budget</td>
</tr>
<tr>
<td>Public Projects</td>
<td>25 % of Budget</td>
</tr>
<tr>
<td>Fraunhofer Projects</td>
<td>25 % of Budget</td>
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**Infrastructure**

Fraunhofer IMS offers a wide range of services and production of in silicon based devices and systems.

The fabrication takes place in class ten cleanrooms, wafer-testing rooms and an assembly-line with together more than 2500 square meters.

**Fraunhofer IMS CMOS Wafer Fab**

<table>
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<tr>
<th>Wafer size</th>
<th>200 mm (8 inches, 0.35 µm)</th>
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<tr>
<td>Cleanroom area</td>
<td>1300 square meters</td>
</tr>
<tr>
<td>Cleanroom class</td>
<td>10</td>
</tr>
<tr>
<td>Employees</td>
<td>app. 120 in 3 shifts</td>
</tr>
<tr>
<td>Capacity</td>
<td>&gt; 70,000 wafer/year</td>
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**IMS Production and Development**

Fraunhofer IMS develops, produces and assembles smart sensors, integrated circuits and discrete elements (ICs and ASICs). It also offers the fabrication of devices on a professionally managed CMOS production line in small to medium quantities.
In the new microsystems technology lab (MST-Lab) we integrate different micro- and nanofunctions directly on top of the signal processing CMOS circuits. This procedure is called post-processing. (600 square meters)

The ICs are assembled in the cleanroom (400 square meters) of Fraunhofer IMS assembly facility. This facility supports the production of ICs in ceramic packages or as COB (Chip on board, COB). COB assembly is available from small quantities to several million units per year.

Supply and Service
The Fraunhofer IMS offers R&D services tailored to our customer needs, providing efficient solutions ranging from the initial studies to the series products.

Cooperation possibilities:
- Studies and feasibility studies
- Consulting and concept development
- Demonstrator and prototype development
- Chip production (ASIC Production)
- Development of soft- and hardware
FRAUNHOFER IMS
BUSINESS FIELDS AND
CORE COMPETENCIES
The Fraunhofer IMS conducts research and development in many different application areas including:

- Automotive
- Medical
- Consumer
- Smart Buildings
- Communication
- Aero Space
- Logistics
- Industrial Automation
- Semiconductor Industry

These applications are served by our business fields:

- CMOS process
- ASIC design und development
- Sensors
  - Pressure Sensors
  - Image Sensors
  - Infrared Sensors
  - Bio Sensors
- Embedded systems hardware and software
- Wireless systems, ICs and transponders
- Smart Buildings

1. CMOS Process and Assembly

Based on standard CMOS process technology, IMS develops customer-specific processes and special options for standard processes (e.g., capacitors, polysilicon and thin-film resistors, high voltage transistors, EEPROM, OTP and several types of sensors).

Pressure-Sensor-Process

With a clear view on the needs of a rapidly growing sensor market, IMS leveraged its long experience in research and development of CMOS-compatible integrated sensors to establish micro-mechanical pressure sensors as one of its product lines.

At the heart of this product line is a pressure sensor that is integrated into standard CMOS technology. This micro-mechanical pressure sensor was designed for a large range of pressures, and can be monolithically integrated with many electronic devices, e.g. MOSFETs, capacitors, resistors or EEPROMs. The layout of the pressure sensor determines its pressure range, as the membrane’s stiffness is directly related to its diameter.
High Temperature SOI Process

The high temperature SOI CMOS process uses SOI substrates for the production of ASICs that operate at temperatures of up to 250°C.

Only fully CMOS compatible process steps are used to manufacture not only standard CMOS circuit elements, including EEPROM, but also silicon based sensors, actuators and power devices.

Power Devices

In close cooperation with industrial partners, Fraunhofer IMS provides a 600V-CMOS-process for half- and full bridge driver chips for IGBTs. Also a novel discrete power MOS transistor process based on trench technology has been developed at IMS. It features an ultra low on-resistance so that transistors with less than 1 mOhm on-resistance can be realized on a small die, while keeping the number of process steps low. Such low loss switches are used in power supply, automotive and other low voltage applications.

CMOS Fabrication

Fraunhofer IMS provides numerous semiconductor production services in its 200 mm CMOS production line. The professionally managed class 10 clean room has more than 1300 m² floor space. The 24 hour, 7 days a week operation ensures the uniform quality of our products.

The Fraunhofer IMS production line especially caters to the production of smaller and medium quantities of ASICs. The production line operates under an ISO 9001:2000 and TS 16949 certified quality management system, assuring stability and reliability of products and production. Timely, reliable and customer-oriented production is our and our customers key to success.
2. Sensors

Pressure Sensors
The basic element of our pressure sensors is a surface micromechanical sensor that is fabricated using standard CMOS processing equipment. These sensors can be realized for a wide range of pressures, sharing a single chip with all electronic devices available in a CMOS process, e.g. MOSFETs, capacitors or EEPROMs. The sensors can be configured as absolute with capacitive readout. The necessary signal conversion, linearization and amplification circuits are realized on the same chip, effectively eliminating interference on sensor wiring that is a major issue for discrete solutions. We have already created a variety of innovative products using this monolithic integration of sensors and signal processing functions like programmable amplifiers, sensor linearization, temperature compensation or wireless interfaces.

The layout of the sensor element determines its pressure range, which may be situated between 0.5 to 250 bar, as the sensor diameter controls the stiffness of the membrane: Smaller and stiffer membranes shift the pressure range to higher pressures. Thus the sensors are suitable for the measurement of pressures ranging from blood, air, and tire pressure all the way to hydraulic oil pressure. The small size of the sensor and its associated electronics enables innovative medical applications for the in vivo measurement of the pressures of blood, brain, eye or other body fluids.

CMOS Image Sensors
Fraunhofer IMS image sensors are based on CMOS technology, which enables the monolithic integration of sensor and circuit elements on a single chip. This integration is used e.g. to control the sensitivity of each individual pixel to avoid blooming. Fraunhofer IMS has developed a dedicated 0.35 µm Opto CMOS process.

A wide range of CMOS image sensors has been developed for our customers and in research projects. The realized sensors include high dynamic range sensors, high speed sensors – which deliver 1000 high quality images per second – and high-resolution sensors with “region of interest” function for faster readout of subsections of the pixel array. The CMOS image sensors suppress smearing and blooming effects and always deliver sharp images. Electronic high-speed shutters enable the realization of 3D imagers base on laser pulsed based time-of-flight measurement.
Infrared Sensor
The demand for uncooled infrared focal plane arrays (IRFPA) for imaging applications is constantly increasing. Examples for the application of IRFPAs are thermography, pedestrian detection for automotive, firefighting and infrared spectroscopy.

IRFPAs consist of an array of microbolometers located on top of a CMOS substrate which comprehends the readout circuit. Typical array sizes are for lowcost applications 160 x 120 or 320 x 240 pixels. State-of-the-art IRPGAs achieve VGA-resolution with 640 x 480 pixels.

The microbolometer is a special infrared sensor. The IR-sensitive sensor element based on the principle for a microbolometer is fabricated by post-processing on CMOS wafers. The microbolometer converts the infrared radiation into heat energy and this induces a temperature rise resulting in a change of the electrical resistance. Typical microbolometers have pixel pitch values of 35 µm or 25 µm.

Biosensors
Biosensors for point-of-care and home diagnostics are increasingly asked for. Therefore Fraunhofer IMS advances in the development of a new generation of biosensors. These special sensors are developed in the Microsystems Technology Lab where standard CMOS circuits are prepared for or – in future – combined with bioactive layers. Typically, additional metals or oxides are added, as well as special surface treatment and activation or the dispersion of anchor chemistry for later analyte receptor immobilization. This new technology is called post-processing and it enables the production of different sensors for different applications by joining biosensitive layers with CMOS electronic readout circuitry. This “Bio to CMOS” processing leads to Biohybrid Systems.
3. ASIC Design
The development of analog, digital and mixed analog-digital integrated systems is a core competence of Fraunhofer IMS. Application specific integrated circuits (ASICs) enable our customers to provide cheaper and more powerful products. We offer the full spectrum from custom to IP-based ASIC solutions.

Full-custom ASICs are designed from scratch to accommodate the specific requirements of the customer, providing a highly optimized product. The IP-based ASIC is based on proven generic components, with lower design time and cost. Using a mix and match approach both design styles can be combined to leverage the benefits of both.

The close co-operation with our in house CMOS production line provides a seamless and efficient path from concept to series production. Our long experience in the development of integrated circuits, starting from concept through design, layout, and fabrication to testing ensures a short development time and a minimized design risk.

Our fields of design expertise are:
- Embedded microcontroller
- High-temperature ASICs
- Smart power integration
- Non-volatile memories
- Mixed-signal design
- Sensor transponder

Beside standard ASIC solutions for all kinds of applications, ASICs with sensors and sensor signal processing integrated on a single chip have been realized.

These ASICs often combine our core competences in ASIC design,
- System-on-Chip (SoC) solutions,
- Mixed-signal signal processing and
- Integration of RF building blocks for wireless energy and data transfer.

Our customers benefit from our research in these areas, which provides viable solutions for their applications – applications that demand miniaturization, energy-efficiency, cost-optimization and reliability.

4. Wireless Systems and Transponders
A core-competence of Fraunhofer IMS is the development and realization of wireless systems. Research and development focuses, among other things, on wireless sensor networks. These networks comprise autonomous sensor modules that are distributed over a large area or volume, and measure physical, chemical and other quantities. The measured values are transferred to a central agency, making use of intermediate nodes for data transfer, or they can be used by similarly distributed actor modules for decision-making and control processes.

Development in this field includes new methods for communication (e.g. protocol stacks, localization) and the realization of cost-efficient, miniaturized components. The realization of new products in an efficient and timely manner is facilitated by the use of modular hardware and software components that allow a quick adaptation to application requirements.

The advantages of wireless sensor networks were successfully demonstrated in some projects.

Important applications of wireless sensor networks are in the field of:
- Industrial automation, e.g. logistics and inventory control.
- Agriculture e.g. monitoring of air and soil parameters.
- Facility management, e.g. remote monitoring of buildings and infrastructure elements.

Our customers face a number of challenges that are addressed by our R&D activities. One set these activities addresses tools for network development, deployment and maintenance. Others address the field of energy harvesting, the ability to extract module power from the environment and obviating the need for batteries or power cables.
The transponder systems unit at the Fraunhofer IMS offers system solutions for the integration of novel portable or stationary transponder read-write devices and base stations into smart network-systems. It also provides base stations for transponder ASICs with integrated micro sensors developed at Fraunhofer IMS, thus offering complete system solutions. These transponder systems are used in smart buildings and vehicles, industrial automation, medical devices and logistics.
5. Smart Room & Building-Solutions
At the Fraunhofer-inHaus-Center, Europe’s leading innovation center for smart homes and buildings, IMS cooperates with six Fraunhofer-Institutes and nearly 100 industrial partners to develop, test and demonstrate innovative solutions of all kinds for different application fields in smart buildings. In detail IMS offers research, development and complete systems-solutions to component and systems manufacturers, builders and operators of homes and commercial buildings for new and added value functions on the basis of electronics and software.

At the inHaus1-Facility (Smart Home-Lab) new domotic techniques to control lighting, doors and windows as well as heating and ventilation for energy efficiency in homes are developed and tested. One focus lies on solutions for smart metering for more transparency in energy consumption. In the SmartHome-Segment we have also a lot of experience in the field of user interface solutions for easier control of technical equipment in homes. User acceptance tests in the smart home lab guarantee the new industrial products to have a better success chance on the market.

At the inHaus2-Facility (Smart Building-Lab) new technical solutions for commercial properties are being developed, e.g. for new benefits in facility management and building operation, in the operation process of nursery homes, hotels and offices.

One main IMS focus lies on the development of new concepts and electronic systems that provide unobtrusive assistance for elderly and handicapped people in order to maintain a self-determined life at nursery homes with commercial operation and to optimize the care service process. We concentrate especially on solutions like microelectronic sensor networks in rooms with software interpretation of data to get benefits like automatic detection of problems or emergency cases (ambient assisted living AAL).

Another main field of R&D in all inHaus-application segments is energy efficiency, like in the smart home field. In cooperation with component and systems manufacturers and also energy providers next-generation-metering and building automation technologies for energy efficiency are developed, tested and demonstrated.

The inHaus Center offers R&D and complete systems-solutions to builders, modernizers or operators of homes and commercial buildings, to implement complete electronic and ITC systems for new and added value functions. This includes the following aspects:
- Safety and security
- Multimedia
- Support for the elderly
- Energy saving
- Light management
## DEVELOPMENT OF THE IMS

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Capital Investments IMS

15 Mio. Euro

## SELECTED PROJECTS OF THE YEAR 2010

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The semiconductor industry has followed Moore’s law since the early 70s. Doubling or even tripling the performance (integration density, speed) every two years through transistor scaling has yielded a better performance-to-cost ratio of products, generating an exponential growth of the semiconductor market. This in turn allowed an increased investment in equipment and processes, again stimulating the scaling. This “More Moore” approach has been accompanied by roadmapping, especially the ITRS roadmap, and is still a driver of the state of the art technology.

Since a few years, however, there is a new trend evolving. Due to the enormous investment and development costs, “Moore More” is handled by a few consortia on a world-wide basis only, concentrating on the large volume markets (memories, processors). In addition a “More than Moore” approach has emerged, where added value to devices is achieved by functionalities that typically do not scale according to “Moore’s Law”.

Especially in Europe this trend is obvious, where semiconductor companies are seeking their markets by adding power handling capability, robustness or sensing/actuating devices to their CMOS processes. Application areas are to be found in the automotive industry, in industrial or medical electronics, but also in consumer products.

A method to enhance the capability of an integrated device is post-processing or “above-CMOS technology”. CMOS wafers serve as “intelligent” substrates. They may contain sensor readout or driver circuitry, temperature sensors, analogue signal processing, and interfaces to the outside world (analogue, digital, wired or wireless). On top of these CMOS wafers you may now deposit additional layers, structures and devices for sensing and actuating.

Compact, “intelligent” micro- and nano-systems will result. Several advantages arise from post-processing:

- Compact sensors contain application specific interfaces
- The ultra short distance between sensor and readout allows detecting very small signals and it allows reading out arrays of sensors.
- Processing is done with proven semiconductor processing equipment, but may include specialized machines and processes
- A large material variety (compared to CMOS) is available
- Sensor/actor manufacturing is quasi independent from CMOS processing, but sensor and circuit functioning are very closely coupled.

To enable IMS following this emerging technology trend and to enable IMS to react to the requests from our R&D customers from the semiconductor industry but also from automotive and industrial users, we have started a project in late 2009 to set up a facility for post-processing at IMS. A 16 million Euro grant from the European Union, the German Federal Ministry of Education and Research (BMBF) and the Ministry of Innovation, Science and Research (MIWF) of North-Rhine-Westphalia is used for establishing a clean room and selecting and installing equipment for post-processing on 200 mm wafers.

600 sqm of former laboratory space have been transformed to a class 10/100 clean room. The challenge was to integrate a raised floor, a wall system, and all facility interconnections.
despite of the limited height of the existing rooms. Filter fan units provide clean air, a clean wall system separates clean room and service area.

MEMS fabrication will use equipment sets for lithography, deposition, etching, metrology and packaging partly similar to CMOS, partly dedicated to new MEMS processes. Lithography uses 1:1 proximity and a 5:1 wafer stepper, both with front to back alignment capability. The stepper is unique in that additionally to 350nm resolution the front to back accuracy is better than 175nm. Thin and thick photo resist as well as polyimide and red/green/blue colour filters may be processed. Deposition systems range from CVD of dielectric and semiconductor layers to sputtering, evaporation and atomic layer deposition (ALD). Whereas ALD provides high precision thin metal or dielectric films, electroplating yields Cu, Sn, Ni, and Au layers up to several µm thick. Plasma etching is used to pattern metal or dielectric layers. Unique to MEMS processing are Ion Beam etching and Deep Reactive Ion Etching. DRIE offers bulk micro-machining and etching for Through Silicon Vias.

A set of metrology systems guarantees reproducible processing and a quick feedback for process development.

Packaging equipment, using this term in a very broad sense, comprises of wafer-to-wafer bonding, chip to wafer bonding, grinding and thinning for chip scale packages, but also for structures made of single crystalline semiconductor layers and devices on top of the CMOS wafer.

At the end of 2010, the new clean room is now “ready for equipment”. Most of the machines cited above have been ordered, several are already delivered and have been installed, basic processes are available, and several projects are well on the way to support our customers.

The developments we are offering range from consulting, delivery of individual process steps for process modules, both interesting for semiconductor and MEMS companies, to the development and delivery of complete sensors on CMOS dedicated to industrial, automotive and medical users.

Two groups of scientists and technicians support the new MEMS facility. The operating group cares for machine installation, maintenance, and process step development as well as organising clean room and facility operations. The MEMS development group devises new device concepts from specification over simulation, prototype fabrication, characterization and tests. Close cooperation with the CMOS development groups, CMOS operations and facility allows the MST lab to benefit from synergy effects and guarantees true integration of sensors and actuators on top of our CMOS. Last but not least our circuit design groups at IMS contribute their know-how in analogue and mixed signal circuits to complete the developments on fully integrated single chip “intelligent” micro- and nano-systems.

Several projects have already been started or even finished in the new facility. We have developed a doped amorphous silicon layer to be integrated onto custom CMOS wafers stemming from a silicon foundry. Finally this layer was transferred to our customer's facility. Electroplating is used to enhance CMOS current driving capability and as a basis for SLID technology (soldering with solid liquid interdiffusion).

Pressure sensors and optical sensors will be integrated on top of our CMOS wafers. The most complex process developed so far serves the integration of a micro-bolometer array on top a readout circuit.

The cross section in Fig 2 depicts typical steps of CMOS followed by post-processing to integrate a sensor on top: a planarised surface of the CMOS, followed by additional metal layers, surface micro-machining exploiting a sacrificial layer with the thin sensor membrane on top and provisions to allow chip scale packaging. In addition we are working on bio-sensors integrating highly specific detection layers to
get marker free sensors. Nano-structures like semiconductor nano wires or carbon nano tubes will be applied to enhance sensitivity.

Post-processing on CMOS is the way IMS has chosen to advance CMOS applicability, to generate new devices and to serve our customers. The new Microsystems facility at IMS is ideally suited to support this goal.
Introduction
The detection of light in the extreme ultraviolet region of the spectrum (EUV or XUV, 4 – 50 nm) is not possible with standard front side illuminated CMOS image sensors as the radiation is almost completely absorbed in the dielectric layers that cover the silicon. This required the use of back-thinned and backside illuminated image sensors or focused ion beam (FIB) procedures for EUV image sensors. With the development of the deep optical stack etching (DOSE) process enhancement the production of pure CMOS front side illuminated EUV photo diodes has been enabled.

Applications
The detection of EUV radiation is part of many scientific research efforts, for example solar EUV imaging or microscopy of biological samples in the so called water window (2.3 – 4.4 nm) where water becomes transparent but carbon absorbs the radiation. Radiation with 13.5 nm is also used in the next generation lithography called EUV-L, which is supposed to be used for technology nodes with feature sizes of 15 nm and below. EUV-L still suffers from many unsolved problems, one of which is the inspection speed of masks and mask blanks. The DOSE process enhancement allows the development of specific image sensors for the mentioned applications, for example fast yet sensitive image sensors for EUV-L mask blank inspection.

The process
The underlying CMOS process used for the DOSE process is a 0.35 µm mixed signal process. For the DOSE process a poly-silicon layer is deposited in photo active regions and the chip is processed until the pad opening. At this point a photoresist is applied and the pad areas are opened together with the photo-active areas lithographically. Using the standard pad opening etch the silicon nitride passivation is removed completely and the silicon oxide is removed partly in photo active regions. After a reapplication of the resist only the photo active regions are opened lithographically. Subsequently the remaining oxide on top of the polysilicon stopping layer and the stopping layer itself are removed. This leaves only a thin thermal oxide on top of the silicon in photoactive regions. This thin thermal oxide serves as an etch stop and protects the silicon surface. A schematic illustration of the DOSE process is shown in Figure 1, a SEM image of 7 µm x 7 µm DOSE photo diodes is shown in Figure 2.

Figure 1. Schematic illustration of the DOSE process. a) CMOS process until pad opening. b) Photo resist is applied, pad regions are opened together with photoactive regions lithographically and pad etching is performed. c) Photo resist is reapplied, photoactive regions are opened lithographically, remaining layers (oxide and polysilicon) are etched.

Figure 2: SEM cross section of DOSE photo diodes with a size of 7 µm x 7 µm.
The sensitivity of a photo diode can be described by its quantum efficiency. The quantum efficiency is the amount of electrons detected per impinging photon, divided by the number of electron hole pairs that are generated upon absorption of a photon. It is calculated from the photon energy, the photo current of the diode (corrected by the dark current and in this case without external bias), the beam power that hits the photo diode and the number of electron hole pairs that are generated per absorbed photon.

The quantum efficiency of DOSE photo diodes has been characterized at the PTB’s (Physikalisch Technische Bundesanstalt) XUV beamline at BESSY II, Berlin, in cooperation with the Fraunhofer ILT. The result for an array of 43 x 43 diodes with a size of 7 µm x 7 µm is shown in Figure 3. A quantum efficiency of around 50% at 13.5 nm is obtained, which is comparable to state of the art backside illuminated image sensors.

**Conclusion and Outlook**

Using the DOSE process extension photo diodes have been manufactured employing only common CMOS fabrication tools, which feature sensitivity to EUV radiation comparable to state of the art backside illuminated image sensors. As no expensive back-thinning or FIB processes are needed, this allows the development of cheaper application specific image sensors. Currently an imager with DOSE photo diodes is planned that will feature an increased frame rate compared to available EUV image sensors. The sensor will feature a resolution of 1280 x 960 pixels, a pixel pitch of 12 µm and a maximum frame rate of 200 fps. It is designed to improve, for example, the scan speed of inspection tools in this wavelength range.

Future work will focus on reducing the thickness of the thermal oxide in photo active areas in order to improve the sensitivity.
Bolometers are used as sensing elements for the detection of IR-radiation in the LWIR (8 ... 14 µm) range. A new kind of diode bolometer can increase the thermal resolution of infrared detectors by reducing the noise of the sensor element. This is achieved by using a mono-crystalline substrate for the bolometer instead of an amorphous sensing layer which is typically employed in conventional bolometers. A mono-crystalline diode reduces the 1/f-noise and therefore increases the signal to noise ratio. The diode bolometer can be integrated by post-processing into a process flow based on CMOS-readout circuits to ensure mass production.

**Introduction**

Amorphous silicon [1] or vanadium oxide [2] are frequently used as the temperature sensing materials for standard microbolometers. The drawback of these amorphous materials is their high electrical 1/f-noise, which limits the signal to noise ratio. A promising way to limit 1/f noise is the use of mono-crystalline materials and it has been shown that diode microbolometers can be formed in mono-crystalline silicon [3]. However, the need for thermal isolation requires that the diodes are suspended from the bulk material by removing the underlying silicon substrate material. This limits the fill factor and makes it impossible to have a CMOS read-out circuitry directly under the pixel. A solution to this problem is to bond an additional sensor wafer to the wafer containing the CMOS read out circuit [4]. This approach combines a high fill factor and the possibility to integrate the read-out circuit in the proximity of the pixel with a mono-crystalline sensing material. Fraunhofer-IMS has developed a thermally isolated single-crystal silicon diode as a detector for microbolometers.

**Test-structure**

To determine the characteristics of the diode bolometer different single-crystal SOI diode test structures have been fabricated as shown in Fig. 1. It is possible to use this kind of test structure due to the fact that the thermal and electrical characteristics of a mono-crystalline SOI diode test structure are very similar to those of a diode bolometer, but without the need for a sacrificial etch process. An typical geometry of such a test diode is shown in Fig. 2.
Temperature DC-model
A complex diode model of the temperature dependent IV-characteristic of a SOI-pin-diode is shown Fig. 3.

This model describes the change of the ideality factor and the saturation current as a function of the temperature and the operating point. The comparison of the measured and modeled temperature dependent IV-characteristic is depicted Fig. 4.

Using the spice simulation software it is possible to numerically determine the temperature coefficient of the current as shown in Fig. 5.

Noise
The thermal resolution of an IR-detector based on a diode bolometer is limited by the noise of the pn-junction. To determine the noise of the component, even at extremely low frequencies, a noise measurement station is necessary (Fig. 6). A good shield against low-frequency electromagnetic radiation is achieved by using an enclosure consisting of two layers, Mu-metal and aluminum. With this measurement setup it is possible to measure noise down to $10^{-26}$ A/Hz and with frequencies as low as $10^{-1}$ Hz.

Readout-circuit
Typically, bolometers are read out by an integrator which converts the electrical current change due to infrared radiation into an analog voltage. This read out principle is used for the determination of the theoretical thermal resolution. It is shown that the influence of the shot-noise with respect to the resolution decreases clearly with higher currents of the diode bolometer. However, with higher bolometer currents, the negative influence of the 1/f-noise regarding the resolution
gets stronger and the decreasing temperature coefficient strengthens this effect. Measurements using test structures indicate a possible NETD of <100mK.

Process flow
A “low temperature direct wafer bond” process step was developed to enable the production of the mono-crystalline diode bolometer (Fig. 7).

This process step facilitates the bonding of the SOI sensor wafer with the CMOS wafer at low temperatures. Subsequently, during the wafer-grinding step, the back-side of the silicon based sensor wafer is grinded down to 5µm over the buried oxide. This is done so that the silicon can be selectively etched away afterwards. The remaining mono-crystalline bolometer membrane itself, which is placed above the CMOS wafer, can then be electrically connected with the CMOS wafer (Fig. 8).

Fig. 9 shows the geometry structure of a diode bolometer.
In a final release step, the membrane can be thermally isolated from the substrate by removing the sacrificial layer as shown in Fig. 10.

The measured vacuum level reaches $p<1 \times 10^{-2}$ mbar. This vacuum level fulfills the requirements for the thermal isolation of a bolometer. To ensure the long term stability a getter is included inside the package. Fig. 12 shows the finished vacuum package.

Vacuum package
To reduce thermal losses by gas convection a vacuum package is required. To realize a reliable vacuum package a bond between a ceramic casing and a silicon lid, achieved by hard soldering the pieces together, is used. The principle of the vacuum package is shown in Fig. 11.

Conclusion
A full process flow for fabricating a mono-crystalline diode bolometer has been established, which is capable to integrate diode bolometer elements above a CMOS-circuit and therefore maximizes the fill-factor of an array. Also, a simple way to realize a Fabry-Perot structure to increase the IR-absorption can be achieved with this process flow. Due to low thermally conductive materials in the bolometer legs, a high thermal isolation can be realized. Diode bolometers can be used as the sensing element of an IR-detector with a high temperature coefficient of current and a low $1/f$-noise and therefore a very low NETD.
References


Abstract
In order to avoid high-temperature-induced degradation of metal interconnects, transistors and other components in CMOS circuits, low temperature processes have to be applied for the post-CMOS integration of MEMS (Microelectromechanical systems). At Fraunhofer IMS novel approaches for the post-CMOS MEMS integration on the basis of silicon-germanium (SiGe) and germanium (Ge) were developed. Poly-SiGe films were deposited with a PECVD process at the substrate temperature of around 380°C, and poly-Ge films were deposited with PECVD at the substrate temperature of around 340°C. Capacitive pressure sensor elements with membranes of PECVD poly-SiGe and PECVD poly-Ge were fabricated. Due to the low deposition temperature of SiGe and Ge, a temperature budget of only 24 minutes at 380°C in the case of SiGe membrane pressure sensor, and a temperature budget of only 26 minutes at 340°C for Ge membrane sensor resulted. Sensor structures were examined with respect to the pressure sensitivity. It was found, that the mechanical properties of the structures with the SiGe or Ge membranes are comparable to the poly-Si structures. Poly-SiGe and poly-Ge films were deposited on metal interconnections in order to form direct electrical contact with the lower metal level. A via-resistance of circa 240 Ω of a poly-Ge via on Ti was measured. The via had a cross section area of 1.5 µm² and a height of 900nm. The demonstrated integration process performed with the low temperature depositions of poly-SiGe and poly-Ge is suitable for the post-CMOS integration of various MEMS structures.

Low-Temperature PECVD of poly-SiGe and poly-Ge films
It was reported, that the deposition of poly-SiGe and poly-Ge films can be carried out at temperatures lower than 450°C with the LPCVD method [1], or with the PECVD method using pre-deposited LPCVD seed layer [2]. It was observed in this study, that poly-SiGe and poly-Ge films can be deposited at the substrate temperatures as low as 380°C (for poly-SiGe) or 340°C (for poly-Ge) solely with the PECVD method, if appropriate deposition parameters are chosen. The main advantage of PECVD method as compared to the LPCVD method is the much higher deposition rate of the former, which effectively reduces the thermal budget of the process. The typical deposition rate of LPCVD SiGe is about 0.6 nm/s [2] as compared to a deposition rate of 7.6 nm/s for poly-SiGe, and 5 nm/s for poly-Ge with the PECVD method, that were demonstrated during this study. In comparison to the method using pre-deposited LPCVD seed layer, our process takes less time, and it is also simpler. The resistivity of the in situ boron-doped poly-SiGe film is about 1.2 mΩ-cm, and that of the poly-Ge film is about 0.8 mΩ-cm.

Capacitive pressure sensor with SiGe and Ge membranes

Figure 1: A simplified process flow for the production of the free standing structures sealed with SiGe or Ge. a) dummy wafer with PECVD silicon nitride; b) sacrificial oxide for the spacer of the “capacitors” and the etch channels are deposited and structured; c) poly-SiGe or poly-Ge films are deposited and structured; d) sacrificial oxide is removed; e) “capacitors” are sealed in vacuum using CVD SiGe or CVD Ge.
In order to verify the deposition process and the properties of the films, capacitive pressure sensor structures were produced. A schematic process flow of the fabrication of the pressure sensors is illustrated in Figure 1. To simulate wafers with completed CMOS electronics, silicon wafers with PECVD silicon nitride on top of them were used. A surface micromachined pressure sensor process at Fraunhofer IMS was modified, and utilized for the demonstration. The structure layer of the membranes was in situ boron-doped poly-SiGe or poly-Ge films. The stress of the films was optimized in such a way, that the structure layer bends lightly to the substrate, after the sacrificial oxide was removed. The capacitor structures were sealed with CVD SiGe or CVD Ge. A measurement of the central deflection of the membranes under different pressure load is depicted in Figure 2 for both materials. A linear dependence of the deflection on the applied pressure was observed. The pressure sensitivity (center deflection/bar) for both types of membranes yields a value of about 200 nm/bar.

Vias of poly-SiGe and poly-Ge

A further aspect of the post-CMOS integration of MEMS concerns the connection of the MEMS with the CMOS electronics. It is possible to in situ dope the poly-SiGe and poly-Ge films in order to generate highly conductive films. Therefore it is possible to deposit these films directly on metal lines in order to form the interconnection between MEMS and the lower metal level and consequently the connection between MEMS and CMOS electronics [3]. This technology was also demonstrated in this study. In Figure 3 a simplified schematic illustration of a via of poly-SiGe or poly-Ge is shown. The metal, which was in direct contact with the poly-SiGe or poly-Ge, was titanium, which guaranteed a good adhesion of the SiGe or Ge films on it. The resistance of the vias were measured by Kelvin via structures. In Figure 4, the measurement of a poly-Ge via, which has a cross section area of 1.5 µm² and a height of 900nm, is shown. The measured value of the resistance of the via amounts to approximately 240 Ω at a current of 5 mA.
Conclusion and prospect

With the successful fabrication of capacitive pressure sensor structures and vias of poly SiGe and poly Ge on metal, it was demonstrated, that the integration process based on the low temperature PECVD deposition of in-situ doped poly-SiGe and poly-Ge films is very promising for the post-CMOS integration of MEMS-structures. Therefore it is an interesting method to produce smart sensors and actuators, which can be more compact and can have more functionalities and smaller sizes.

References:


UniHealth – UNIVERSAL SENSOR SYSTEM FOR THE DETECTION OF ALLERGENS AND BIOMARKERS

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The area of biosensors lies at the interface of physic sciences, technology development and biology. Bridging the knowledge and know-how together will enable biosensor systems which will provide not only sensitivity, selectivity and reliability but also portability at reasonable costs. Micro Electro Mechanical Systems (MEMS) are producible on a large scale, easily fully integrated and can provide rapid responses (1). They are superior to comparatively bulky and expensive laboratory equipment such as enzyme-linked immunosorbent assays (ELISA). Integrated MEMS can provide results through direct electrical measurement and do not require fluorescence testing. Therefore, they can bring the analysis closer to the end user allowing Point of Care Testing (POCT).

Aims of the project:

The UniHealth project aims at developing a label-free biosensor prototype for POCT. The first application is the detection of allergens in foods. The gluten protein has been chosen because 0.7 to 2% of Europeans are affected by the Celiac Disease that generates inflammatory reactions of the digestive system in the presence of gluten. Another allergen is the papain protein present in exotic fruits such as papaya and kiwi. The sensor will be able to tell if foods contain low enough concentration of allergens therefore if they can be consumed by the allergic user.

The second application concerns the detection of the anti-angliosid antibody that reveals the Guillain-Barré syndrome. It is an autoimmune disorder affecting the peripheral nervous system that can cause paralysis. It has an incidence of 1 or 2 persons per 100 000. This biosensor system will be used by doctors in their surgeries or in hospitals.

Sensor system:

The complete sensor system will consist of three parts. Firstly, a preparation step is needed to convert the sample to a liquid form. A device will be developed or adapted from an existing product that will shred, filter and mix the sample with a buffer solution. In this way the user will be able to analyse a wide range of food samples. Secondly, a device will be developed that will contain the microfluidics necessary to handle the liquids (such as pumps, tubings and micro-channels) as well as the measuring and communication circuits. It will be coupled to a handheld (for example a smart phone) or a computer. The calculation and display of results will be carried out by a program developed on the corresponding operating system. Finally, a removable cartridge comprising the functionalised sensor arrays will be inserted for the measurements.

Principle of operation:

The natural resonance frequency of a circular membrane can be expressed as a function of material properties and dimensions (2).

\[ f_0 = \frac{40.8 \, t \, \sqrt{E}}{2\pi \, d^2 \, \sqrt{12(1-\nu^2)\rho}} = \frac{10.2 \, t^{3/2}}{d \, \sqrt{E \, 12(1-\nu^2)m}} \]

Where \( f_0 \) is the natural resonance frequency of the membrane, \( E \) the Young modulus, \( \nu \) the Poisson coefficient, \( \rho \) the density of the material and \( m \) its unloaded mass. The dimensions \( t \) and \( d \) are the thickness and diameter, respectively. From this formula, it is derived that a shift in mass \( \Delta m \) induces a shift in frequency \( \Delta f \) proportional to the added mass. In addition, replacing \( m \) and \( f_0 \), it follows that the mass sensitivity \( R \) is strongly dependent on the diameter \( (R \propto d^4) \) but independent of the thickness.

\[ \frac{\Delta f}{\Delta m} = -\frac{1}{2} \frac{f_0}{m} \]

\[ \Delta f = -\frac{1}{2} \frac{\Delta m}{m} f_0 \]

\[ R = \frac{\Delta f}{\Delta m} = -\frac{40.8}{\pi^3 \rho \, d^4} \sqrt{\frac{E}{12(1-\nu^2)}} \]
The operation principle of the sensor relies on this resonant sensing. The sensor element consists of a free-standing polysilicon circular membrane that can be electrostatically actuated and a selective layer on its surface. This layer will capture only one specific analyte (one of the above-mentioned molecules). In presence of the analyte, the resonance frequency will shift due to the captured additional mass. The membrane and the bottom substrate electrode form a capacitance whose value varies with the deflection of the membrane. Figure 1 illustrates the schematic cross section of the sensor. An integrated circuit measures and analyses the resulting signal. The element and circuits are produced using the IMS pressure sensor 1.2 µm technology and the surface is functionalised by several post-processing chemical steps.

The surface functionalisation will be performed with expertised collaboration partners as the Radbout University Nijmegen and the Wagenigen University within the framework of the UniHealth project.

**Proof of concept:**
To demonstrate the principle of operation, silicon dioxide bumps of different sizes have been deposited onto individual membranes by Focused Ion Beam (FIB). The size of the bumps has been measured and thus the added mass could be estimated. A 6 x 6 x 1 µm³ SiO₂ post deposited in the center of a membrane surface is shown in figure 2. It corresponds to a mass of approximately 93 pg.

The membranes have a diameter of about 96 µm, are 1 µm thick and have a mass of about 20 ng. The smallest added mass represents less than 0.1% of the membrane mass. The sensor chip is mounted in a ceramic package that is then contacted to the actuation and measurement equipment through a printed circuit board. The experimental set-up is shown in figure 3. The sample is placed in a chamber that has several inlets for an external pressure monitoring and electrical cabling to the sensor. It is possible to measure in vacuum conditions. The deflection of the poly-silicon membrane is measured...
through a glass window by optical interferometry while the frequency is scanned. The sensors are actuated by a sinusoidal signal of 3V amplitude.

Figure 4 shows the deflection vs. frequency measurements for four membranes at atmospheric pressure. It is observed that the additional mass induces a shift in the resonance frequency peak. The resonance frequency lies around 2.5 MHz.

![Figure 4: Deflection amplitude as a function of frequency of 96 µm membranes with different silicon oxide masses deposited by FIB. The deflection has been measured by optical interferometry at atmospheric pressure and the excitation is a sinusoidal signal of 3V amplitude.](image)

The resonance frequency in function of the added mass values is depicted in figure 5. The sensor membranes exhibit a mass sensitivity of about 680 Hz/µg when the data is linearly fitted. This is promising since it is exceeding the published theoretical value of 30.2 kHz/µg for 18 µm diameter membranes resonating at 18 MHz (3). Indeed, taking into account the dependence of the sensitivity with the diameter and assuming the material is the same, the equivalent sensitivity would be 37 Hz/µg for a 96µm diameter membrane. In addition, the membranes produced by the IMS 1.2 µm technology have the advantage of operating at lower frequencies, requiring less operating voltage and the sensors can be monolithically integrated with read-out circuitry.

\[
Sensitivity: R = \frac{\Delta f}{\Delta m} = -680 \text{ Hz/µg}
\]

The resonance frequency in function of the added mass.

![Figure 5: Extracted resonance frequency in function of the added mass.](image)

Conclusion and outlook:
The utilisation of resonant sensing and the Fraunhofer IMS pressure sensor membranes as a signal transducer shows promising results for bio-sensing applications. In addition, the MEMS structures can be mass produced using a CMOS-compatible process thus providing the wished integration of measurement and signal processing circuits. Furthermore, it can be used as a biosensor platform since different surface functionalisations, applied after the semiconductor fabrication steps, can provide the selective recognition of biomolecules such as allergens or biomarkers.

The next steps of the project are to demonstrate the operation with electrical measurement and in fluids. Then functionalised surfaces will be used to verify the effect of the binding of the...
target molecules. Finally, the sensor element will be integrated in a resonator circuit that will output the real-time resonance frequency.

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Since the institute’s foundation in the mid 1980’s the scientists at the Fraunhofer IMS have been dedicated to furthering the evolution of CMOS electronics and CMOS process technology. Following this tradition of innovative, leading-edge research, Fraunhofer IMS in 2009 became one of the founding members of the High Dynamic Range Low Noise (HiDRaLoN) project. Together with 15 partners from leading institutions across Europe, Fraunhofer IMS is currently working to establish a new generation of high dynamic range imagers catering to a multitude of applications. Covering fields like novel X-ray and computed tomography imagers, HD broadcast camera chips, lenses and correction algorithms as well as machine vision systems and 3D imaging systems, HiDRaLoN will push the limits of available CMOS imager technology to a new level.

1. Project overview

1.1. Project goals
Currently different driving forces can be identified on the CMOS imager market. For example high definition camera systems are constantly pushing the requirements for imager resolution and readout speeds. In addition, emerging technologies for 3D applications call for sub-pixelation and lenticular lenses on top of the imagers. Furthermore, industrial automation applications require advances in dynamic range to be able to cope with adverse lighting scenarios. Hence, the most urgent needs of the industry can be boiled down to a miniaturization of the pixel cell at a simultaneous increase of the pixel performance and the in-pixel signal processing power. Although the details of custom implementations for certain applications may differ, high dynamic range and low noise are always of key importance at any stage in the imager design and evaluation cycle. Thus, combining the research efforts and experience of many of Europe’s major imager designers, HiDRaLoN aims at generating mutual benefits in terms of pixel and imager technology, modeling of electrical and optical crosstalk and correction algorithms.

With these considerations in mind the HiDRaLoN consortium has set a number of project goals to be reached within the three year project duration. First of all the efforts are focused on improving the dynamic range of CMOS imagers up to 120 dB whilst cutting their noise by 50 per cent and still maintaining crucial properties like resolution, sensitivity, low image lag and high quality. Reflecting the aforementioned wide range of target applications, sub-clusters among the project partners have been established in order to develop a total of five custom imagers for the medical, broadcast, 3D vision, machine and industrial vision segments. At the end of the project three imagers will demonstrate the improved performance in the 3D vision, medical and broadcast markets. The project work is rounded off by detailed work on imager and lens defect correction algorithms as well as interconnect and system design studies.

1.2. HiDRaLoN project organization
As illustrated in Figure 1, the HiDRaLoN consortium incorporates eight European companies, who are active in the field of imager or camera design. Apart from these industrial partners, five research institutes and universities as well as one corporate research center are also involved in the project (see Figure 2). The close collaboration of all partners guarantees a high degree of know-how exchange via regular meetings, reporting cycles and a constant supervision by both public funding authorities and the Catrène office.

Figure 1 Overview of the industrial partners of the HiD- RaLoN consortium.
One special feature of the project is that, due to its high impact and visibility, it has attracted over 10 European companies to the adjoined user group. These companies are seeking to secure their position in their respective markets by having regular exchanges with the project partners and by having direct access to the project results.

Within the project Fraunhofer IMS coordinates all specification, benchmarking and modeling work. Furthermore, the institute also holds an unique position among the partners as it is the only institution which maintains a CMOS production facility and can therefore cover all project phases from design and simulation to chip production and assembly in-house.

Regarding the research activities in HiDRaLoN Fraunhofer IMS is mainly involved in the area of 3D vision imagers for automotive, logistics, safety/security and entertainment applications. The following section will present a general overview over this imaging concept and the related detector technology.

2. 3D Time-of-Flight imaging

2.1. Introduction

Due to increased level of automation in modern fabrication and logistics chains as well as in driver-assistance systems for automotive applications and in controller-free human-computer interfaces, 3D range measurements are quickly gaining ground. To address these needs Fraunhofer IMS propagates a measurement approach based on pulsed laser light, which, similar to Radar or Lidar applications, is reflected from a distant object and thus allows the determination of the object’s position relative to the observer. However, as it relies on an active measurement method with a pulsed laser beam, this concept can circumvent limitations present in continuous-wave laser illumination systems or in fully passive 3D vision methods like stereoscopy. In detail, the hardware requirements of pulsed 3D Time-of-Flight (ToF) devices are significantly lower compared to stereoscopic systems, as only one camera with a simple laser diode setup and only very little CPU processing power are required. The advantages of 3D ToF measurements with pulsed laser light over continuous-wave illumination lie in the non-ambiguous range information, the inherent background light suppression and the easier compliance to eye safety regulations. The last point is based on the fact that the invisible IR-laser beam, which, albeit being quite powerful, is only active for a few dozen nanoseconds and therefore does not harm the retina.

2.2. Technological advances

In spite of the rather simple 3D ToF principle, which is basically only a runtime experiment, regular photodetector elements are unsuited for 3D ToF measurements. The cornerstone of a distance measurement with pulsed laser light is the speed of the photodetector element. Here speed does not only refer to the time it takes for the generated charge carriers to reach the readout node but also to the ability to almost instantaneously switch between different such nodes. Figure 3 illustrates these points on a novel detector structure proposed by Fraunhofer IMS. As shown, the so-called lateral drift-field photodiode features a lateral doping concentration gradient along the photosensitive area. This gradient is introduced in a single, additional implantation step and it generates a lateral drift-field, which quickly sweeps the charge carriers towards the collection gate (CG).

By this means the LDPD significantly speeds up charge collection compared to regular diffusion-based photodetectors. Figure 4 shows a measurement of the charge collection times in different sensor structures. It is evident that under 3D ToF
conditions, i.e. 30 ns laser pulses at approximately 900 nm wavelength, the LDPD surpasses the charge collection performance of an equally large photogate (PG) structure by a factor of 4 and that of a pinned photodiode (PPD) by a factor of 2.

Having explained one aspect of the speed requirements, it is possible to address the second problem. Figure 5 illustrates the general clocking scheme of a 3D ToF sensor operating with pulsed laser light. Initially a laser pulse of width $T_{\text{pulse}}$ is emitted by the system. It then takes the light a certain amount of time $T_d$ to travel to a distant object and to return to the imager. By synchronizing the readout of the detector to the emitted laser pulse, the distance information can be obtained. This is handled through two CCD-like transfer gate (TG) structures, which steer the generated charges either into the floating diffusion (FD) readout nodes 1 or 2. As shown, part of the reflected pulse is detected in FD1 and the rest is accumulated in FD2. The difference signal between FD1 and FD2 finally constitutes the distance information. This fast switching requirement was tested experimentally under laser illumination. Figure 6 shows the device’s signal amplitude as a function of the delay time $T_d$. Considering FD1 it is evident that basically all charges are collected in FD1, if no delay between incoming and returning pulse is present, i.e. if the distance is zero. On the other hand if it takes the light more than 30ns to travel to the object and back, all charge is seen in readout node FD2, which is also according to expectation.

Note that this measurement approach provides valuable additional information, as it also yields a measure of the objects reflectivity. With the ratio of FD1 to FD2 giving the distance information and the sum of both signals determining the reflectivity, possibly erroneous distance measurements can be prevented.

Apart from the improvement in device speed, the proposed concept also exhibits low noise levels. This is because the p+ implantation in the photoactive region pushes the potential maximum away from the surface and thus limits recombination effects.
Even though already the first results obtained with LDPD structures on the test chip shown in Figure 7 look very promising, Fraunhofer IMS is also currently optimizing and evaluating standard photodetector structures like PG and PPD for 3D ToF applications.

3. Conclusion
With the HiDRaLoN project the Fraunhofer IMS advances its role as one of Europe’s key centers for CMOS imaging technology and simultaneously maintains a close connection to many European imager designers. In the field of 3D Time-of-Flight imaging novel technologies, which will benefit a wide range of applications, are currently under research.

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AN 868 MHz PASSIVE TEMPERATURE SENSING TRANSPONDER USING A SELF-BIASING UHF RECTIFIER WITH – 10.5 dBm SENSITIVITY IN LOW-COST 0.35 µm CMOS

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Wireless energy transmission via electromagnetic waves can be used to generate the supply voltage for micro-power ASICs such as RFID tags or simple sensor nodes [1]. These Sensor nodes can be used in logistics applications, for example in temperature monitoring of products during transportation. Delivery trucks or warehouses can be supplied with RFID readers that generate the electromagnetic field to communicate with the sensor nodes of different objects. The sensor transponders do not require a battery, but generate the supply voltage from the antenna voltage. Therefore, the individual nodes can be very light and cheap. The Villard circuit (sometimes referred to as Dickson charge-pump or Greinacher circuit) is typically used to multiply and rectify the RF voltage from the antenna [2]. The power sensitivity $P_{min}$ of this circuit is a critical figure of merit in order to reach a large operating distance of the passively powered device. $P_{min}$ is defined as the minimum input power that generates the required output DC supply voltage for a given load current.

Figure 1 shows the chip architecture of the developed passive sensor transponder. Beside the rectifier circuit, the ASIC contains a modem, a clock oscillator, power-on-reset detection, and voltage limitation. The chip also includes a bandgap voltage reference and LDO voltage regulator to generate temperature-independent supply and reference voltages. A digital part manages the communications protocol as well as access to non-volatile memory. The minimum unregulated supply voltage is specified as 1.6V to guarantee reliable operation at all process corners and temperature variation (−40 °C to +85 °C). The average current consumption is 5 μA.

The rectifier sensitivity is reduced by the forward voltage drop of the diodes [3]. Schottky diodes are often used for their high switching speed and low voltage drop (typically 200 mV to 400 mV). However, the substrate losses and series resistance of these devices is not negligible without additional masks to produce well suited Schottky diodes. Diode connected transistors are available in every standard CMOS technology, but their threshold voltage reduces the sensitivity. Low-Vt transistors are often available, but Vt is not a precisely controlled parameter. It is influenced by process and temperature variations, and a negative Vt is not acceptable for rectification.

An analysis [1] of the voltage conversion yields $V_{out} = 2^n (V_i – V_{drop})$, where $V_{out}$ is the output DC voltage, $n$ is the number of stages, $V_i$ is the input voltage amplitude, and $V_{drop}$ is the forward voltage drop of each rectifying device. The value of $V_{drop}$ depends on the output load current as well as on the specific I(V)-characteristic of the rectifying device. In addition to this voltage transfer characteristic, the input impedance of the rectifier determines the power sensitivity. A quantitative study of the input impedance was presented in [2]. The input resistance and the input capacitance depend mainly on the output current consumption as well as parasitic losses in bulk-CMOS technology. In typical process technologies without additional masks or well controlled low Vt, the voltage drop across the rectifying devices remains a limiting factor for the operating range of passive devices [3].

Several techniques have been developed to eliminate the effect of Vt by means of gate biasing techniques [4], [5]. Figure 2 shows a single rectifier stage where the gate of the...
CMOS CIRCUITS
AN 868 MHz PASSIVE TEMPERATURE SENSING TRANSPONDER USING A SELF-BIASING UHF RECTIFIER WITH ~10.5 dBm SENSITIVITY IN LOW-COST 0.35 µm CMOS

PMOS transistor is “pre-charged” with a voltage bias at one $V_t$ below the output voltage of the stage. Correspondingly, the gate of the NMOS transistor is biased at one $V_t$ above the DC input. This way, the transistors act as diodes with 0 Volts $V_t$. NMOS transistors are used in vertical branches and PMOS transistors are used in the horizontal branches, so that all gate bias voltages for eliminating the threshold voltage drop are DC signals. It has been proposed to use a microbattery [4], ferroelectric capacitors [5], or a secondary rectifier [3] to provide the required biasing voltage.

Figure 3 shows the developed self-biased rectifier topology. The first stage, the three intermediate stages, and the two topmost stages have slightly different topologies. The output of the fourth stage provides the supply voltage of the chip, stages 5 and 6 remain unloaded to generate a higher voltage for biasing purposes. In addition to the rectifying transistors, a total of 7 no-mask-added Schottky diodes are still required, as will be explained in the following.

At low input voltage amplitude, the voltage at the output of the first stage is less than one $V_t$, so the bias voltage at the gate of a horizontal PMOS transistor would have to be negative to effectively cancel the threshold voltage drop. A simple remedy to avoid negative voltages on the chip is to replace this PMOS transistor in the first stage with a medium sized Schottky diode (contact area = 10 µm²). All NMOS transistors require a bias voltage that is higher than the output DC voltage of the preceding rectifier stage. However, during the initial start-up phase, the DC voltages have not been generated and the biasing scheme is not in effect. Therefore, to ensure reliable start-up of the circuit, small sized Schottky diodes (contact area = 3 µm²) are placed in parallel to the vertical NMOS transistors to serve as rectifying devices when the threshold voltage drop of the transistors is not yet eliminated. The NMOS transistors in stages 3 and 4 require a bias voltage that is higher than the output voltage of the rectifier (DC_4). Therefore, two additional stages (5 and 6) are implemented to generate higher, unloaded voltages (DC_5 and DC_6) to
supply the biasing circuits for the NMOS transistors in stages 3 and 4. Stages 5 and 6 are implemented without transistors in the vertical branch, because the required biasing voltage for NMOS devices would be higher than the top voltage DC_6.

The biasing circuits are connected to different DC terminals in the rectifier stack in order to minimize the voltage drop across the resistors. This way, the resistor size can be reduced without significantly increasing the load current. For example, the biasing circuit to generate the gate voltage of the NMOS transistor in the third stage is connected between terminals DC_5 and DC_2. The bias voltage is set to be higher than DC_2 by one Vt, so it is almost as high as the potential at node DC_5. Therefore, the voltage across the resistor is close to zero, and the current through the biasing branch is almost negligible when all capacitors are fully charged during "steady state" operation.

The measured IC (figure 7) contains the complete analog part of the sensor transponder with the presented rectifier circuit. The chip area is 1.7 mm x 1.3 mm including the pads. A large part of this area is used for capacitors to achieve sufficient PSRR of the regulator and the references during temperature measurement. Figure 4 shows the measured data signals during wireless communication. Figure 5 shows the rectifier output voltage as a function of the input power for the proposed circuit, as well as for the rectifier presented in [3] and the conventional Schottky diode approach. All three circuits were fabricated and measured in the same CMOS process. The proposed circuit presents a sensitivity improvement of 4 dBm compared to the conventional circuit and generates a significantly higher output voltage than the circuit in [3]. The measured current consumption is 3 µA (without the digital part) at 1.6 V, in agreement with simulation. Figure 6 shows the measured DC output voltage as a function of the load current. The achieved power sensitivity of the presented IC is still lower than some reported values for non sensor RFID tags [1]. This is due to the fact, that the sensor node requires significantly more power.
CMOS CIRCUITS

An 868 MHz Passive Temperature Sensing Transponder Using A Self-Biasing UHF Rectifier With ~10.5 dBm Sensitivity in Low-Cost 0.35 µm CMOS

(1.6 V x 5 µA = 7.5 µW, including digital) than simple RFID tags (1 V x 1 µA = 1 µW, [6]).

References:


Combining standard CMOS wafers with additional processing steps allows the creation of Micro-Electro-Mechanical Systems (MEMS), which extend the functionality of the chips from electronic circuitry to direct sensor and actuator functions. A sensor function that can be realized with such additional processing is the detection of infrared radiation (IR) in the 7 to 14 µm range. This function cannot be achieved in CMOS structures alone for these longer wavelengths, which are used in thermal imaging applications.

Using an array of MEMS structures (see the article “Thermally isolated monocrystalline silicon diodes as detectors for microbolometers” in this issue for an example) as IR sensor pixels, an IR imaging sensor can be constructed, very much like the conventional imaging sensors for visible light. The sensor element consists of a temperature-dependent resistor suspended above the chip surface on two supports. These supports provide a high degree of thermal insulation, so that the resistor’s temperature is determined by the arriving infrared radiation. The resistor’s temperature-dependent resistance therefore provides a means to convert the level of incoming IR into an electrical signal.

Conventional IR image sensors of this type have followed the same general lines as visible light image sensors. Those sensors are wholly built using CMOS technology (or, equivalently, CCD technology), with a pixel consisting of a sensor area (silicon diode), an integrating capacitor and a switch to connect to an output amplifier or a video ADC. While the IR pixel does not need the diode (its sensing element is the MEMS resistor), but integrating capacitor and the switch are still present. The output amplifier or video ADC usually is realized once for the whole array, with a hierarchy of row and column switches sequentially connecting it to each pixel.

This kind of architecture has several drawbacks: The output amplifier or ADC have to operate at high speeds, as the pixel rate at the output approaches 10Mpel/s for arrays with VGA resolution (640*480 pixels), while providing a resolution of 16 bit or better. These devices run at a high power level and constitute a “hot spot” on the chip, which can degrade the performance of nearby pixels. All signals from the individual pixels to the output amplifier or ADC are analog signals, so very careful routing is required so that they are not subject to interference.

Our new readout architecture (Fig. 1) takes advantage of the silicon real estate under the sensing elements to implement the ADC function, using a massive array of simple and slow ADCs instead of one fast and power-hungry one. This not only eliminates the hot spot, it also uses robust digital signaling to move the image data out of the array. As it is unfeasible to have one ADC for each pixel, adjacent pixels are combined into clusters of pixels sharing one ADC. During the frame period the pixels are converted sequentially, and the results are serially shifted out through the cluster columns. One row of cluster data at a time arrives at the edge of the array, where it is multiplexed into a single output stream.

For low circuit area and robustness, the ADCs were implemented as Σ-Δ ADC converters, consisting of a second-order analog Σ-Δ Modulator and a digital decimation filter using a three-stage sinc filter with a programmable filter order. With a small ADC footprint the size of the pixel clusters can be kept small. This has two beneficial results: the time
available for each pixel increases, improving noise reduction due to the longer integration time. In addition, given a fixed oversampling ratio of the $\Sigma$-$\Delta$ ADC converters, the speed of the analog and digital circuit can be reduced. Therefore the filter algorithm was optimized, yielding a structure consisting of three cascaded integrators followed by rate decimation and a 3rd-order differentiator. This structure has an added benefit in that the filter order can be made programmable by changing the timing of the rate decimation stage. Register word length were minimized by considering the maximum possible result sizes and by using modulus arithmetic. As all ADC converters in the array are working in lockstep, all control signals and clocks are generated centrally outside the array, and are distributed to the converters via drivers distributed along the edge of the array. Thus only the datapath elements of the filter need to be located in the array.

An analysis of the area and power consumption of the data path shows that the former can be reduced by using serial arithmetic, at the expense of an increased power consumption and data clock rate. A fully parallel implementation would require more than 4 times the area of a bit-serial one, but its power consumption is slightly below 1/3 of the bit serial solution. We decided to optimize the area-power product of the circuit, which resulted in using 4-bit serial arithmetic. The power consumption now is about 50% above that of the fully parallel case, and the area just 30% above the bit-serial implementation area.

In order to reduce the area even further, the digital filter was implemented using a full-custom digital design (Figs. 2 and 3). This resulted in dramatic area reduction: while a standard cell layout used about 90000 $\mu$m², the full custom version only needs slightly less then 13000 $\mu$m². As registers were implemented with dynamic latches and multiplexers with transmission gates, both using only NMOS pass transistors, the logic high level of all control and clock signals was set one NMOS threshold voltage higher than the supply voltage of the digital filter. The use of dynamic latches and switch logic also has the additional benefit of reducing the power dissipation within the array. This is not only due to the reduced supply voltage, but also due the reduced capacitive loads these elements present, compared with equivalent circuits implemented as fully complementary CMOS logic.
Testing such an array may seem to be a difficult task at first sight, but by exploiting the structure of the filter circuit it was quite simple to integrate powerful test support with very little overhead. As the data registers are organized as segmented serial registers, the implementation of a full scan path actually is straightforward and has very little overhead. Most of the circuitry needed is also used for the serial reset scheme that initializes the filter before the start of a new conversion, so that only 12 NMOS transistors are needed to implement 4 parallel scan chains in each filter. The scan chains of the clusters in column are connected in series, so that scan data enters the array on the top and leaves on the bottom. The 4 parallel scan chains in each column can be selected for test, or operated in parallel with the same set of input data. In the latter case, comparators in the row multiplexer block can compare the output of 4 reference scan chains with the scan chain outputs of the other columns. The combined output of the comparators is available, together with the reference scan chain data, at the device pins. This scan test/BIST combination reduces scan test time by almost two orders of magnitude. In addition, a true BIST mode was implemented for a functional/at-speed test of the filters. In this mode, a programmable digital $\Sigma$-$\Delta$ modulator in the state-machine block supplies all filters with a $\Sigma$-$\Delta$ data stream, replacing the data from the analog modulators. As all filters run in lockstep, all results must be the same. Like “real” results they are shifted out to the row multiplexer, from which they are transported to the device pins for testing. Alternately, they can be compared like scan test results, providing a means of in-system test.

Implementing the digital filter of the $\Sigma$-$\Delta$ ADC as a highly optimized full-custom layout allowed us to integrate several thousand ADCs on a single chip. It reduced power requirements by almost an order of magnitude, making self-heating of the chip negligible. Leveraging the power of full-custom design comes at a cost: the design time for the filter function, less than a week for an HDL-based standard cell design, was close to 10 weeks for the full custom design. A very careful assessment must be made before committing to a full-custom design, as it has severe impact on design time and cost. In our case, it was simply indispensable to meet the project goals.

The presented work is part of project “FIRKAM” funded by the German “Bundesministerium für Bildung und Forschung BMBF”.
The subject of the cooperative project »SmartForest« funded by the Bundesanstalt für Landwirtschaft und Ernährung (BLE) is the application of transponder technologies and wireless sensor networks with the objective of contributing to the efficiency of silvicultural processes. The project focuses on two aspects: the concept development and application of long-lasting tree labelling tool and the development and implementation of wireless sensor networks for long-term forest monitoring at high spatial and temporal resolution. The cooperation partners are the Leinemann und Hosius GbR (ISOGEN), the MUL Services GmbH and the Nordwestdeutsche Forstliche Versuchsanstalt (NW-FVA).

Tree labelling with RFID
A wide variety of labelling options is available for immediate identification like colour marking and labels made of metal, plastic or paper. Over time, however, many of them may have been removed, damaged or destroyed due to weather, growth or vandalism. To solve this problem, the ideal solution would be to hide the identification marker in a place where time and environment will have minimal effect on system robustness. The solution pursued in the project is to embed RFID tags at the trees and retrieve the identification numbers via a tree-penetrating RF signal. A battery is not present within the RFID tag; instead, energy is received wirelessly from an antenna connected to a handheld reader. Remote and on-demand power transfer allows the tags to remain hidden behind the tree’s bark indefinitely, a considerable advantage toward maintaining longevity and reliability for this type of identification marker.

Tree labelling at this level carries with it some unique application requirements including the need for a relatively long range (more than 50 cm) and small tag sizes coupled with durability to large variations in wood, moisture, and biochemical content in the path between the RFID tag and the reading device. Furthermore, economical aspects are of some importance not only in terms of RFID tags but also in terms of the processes involved.

With respect to the aforementioned requirements project work has focused on the choice of components (i.e. RFID tags, reader, etc.) and the development of dedicated software components (i.e. reader application, system architecture). This work has been carried out by the project partner MUL Services GmbH. As a matter of course extensive field tests have been performed by the NW-FVA and ISOGEN in order to validate the concepts developed and to investigate the interaction of entities of interest. For that purpose around six hundred RFID tags have been attached to seven forest species in various forestry districts.

The results of the field tests showed among others that the amount of time for the installation of RFID tags corresponds to the amount of time needed for traditional methods like colour marking. Furthermore, it turned out that the robustness of the selected devices do meet the requirements and constraints. As a matter of fact, it is impossible to draw final conclusions regarding the long-term readability and durability (in terms of tens of years). However, process improvements are achieved at this stage of development by implementing a seamless flow of information.

Wireless sensor networks for long-term monitoring
Wireless sensor networks provide the ability to measure and record information about the natural environment at high spatial and temporal resolution such as, for instance, long-term monitoring of dynamic phenomena like soil water content, air temperature, air humidity or leaf humidity in small forest areas. Although the supporting communication technologies for low cost, low power wireless networks wireless sensor networks have been greatly improved in the past decade, there are still some research and design aspects remaining, in order to ensure a long-term unattended operation of a sensor network. Furthermore, in forest areas energy harvesters are suitable in a restricted manner only. Hence, the main objective of this particular project has been to improve the operation time of battery powered sensor nodes.
Various components affect energy consumption of sensor nodes (e.g. electronic components, protocol stack and application software). Whereas off-the-shelf electronic components have been used, development efforts have been focused on adjusting software components in terms of minimizing in network communication. In a sensor network, sensor nodes communicate with each other through short-range radios at least with those nodes being in the radio range. In monitoring applications, all sensor nodes are sources, sense environment and transmit sensed data to the sink periodically. In addition to sensed data, each node must transmit other node’s data to the sink. In network communication is mainly affected by the protocol stack providing connectivity within the network. A dedicated protocol stack, enhanced in this project and based on IEEE802.15.4, ensures connectivity and coverage with respect to the reliability of transmission while allowing the sensor nodes to operate in an energy efficient manner (i.e. low duty cycle).

Field tests have been carried out at the Göttinger Wald site in co-operation with the NW-FVA to evaluate aspects of lifetime and reliability in a silvicultural environment. Sensor nodes have been deployed in the test area equipped with sensors to measure soil moisture, air temperature, air humidity and leaf humidity. In order to monitor actual network status, beside sensed data additional data have been transmitted representing network topology, number of transmissions or battery health. The sensor nodes were powered by low-cost alkaline batteries. Their service life is decreased as they are discharged at low temperature, like in the period from December 2009 to March 2010 at the test area. The sensor network has performed flawlessly even under these environmental conditions.

**Conclusion**

The results from this cooperative project show that the utilisation of electronic components in forestry provides the opportunity to improve processes involved in terms of information retrieval and information management. RFID-based tree labelling enables long-term data access as compared to traditional methods which is of some relevance in terms of forest genetic resources. An adapted wireless sensor network technology allows long-term monitoring of phenomena like soil moisture, along with high spatial and temporal resolution while operating unattended.
Abstract
The use of sensor-transponder technologies particularly in medical applications opens valuable possibilities in therapy of human cardiovascular system diseases, e.g. cardiac insufficiency. The application presented here is representative for future applications, where the use of miniaturized passively-powered sensor-transponder systems with high read range is relevant. In the past, load-modulation was developed as a simple technique to transmit data from low-cost ID-transponders to a reader. This technique can be considered as suboptimal for the given challenges in the presented medical and other possible high-demanding applications. Higher read ranges and small antenna dimensions are necessary. In consequence new techniques, especially for data transmission, have to be developed. First of all, the limitations of the load-modulation technique are analyzed. Conventional solutions are then discussed. It is shown that existing solutions could not be used for this specific and future applications. A new data transmission technique called “frequency conversion” is presented. This technique allows data transmission over a greater distance. Measurements in a practical implementation verify the performance of this technique.

I. INTRODUCTION
Medical studies have shown that the treatment of cardiovascular diseases could be significantly improved by a continuous monitoring of physical parameters, deep inside the human body, including blood pressure and temperature. Due to the impossibility of a local battery as power supply, the use of so-called passive transponder systems is of special interest. In the past several RFID-transponders with attached sensors have been developed [1][2][3]. These transponders work with state of the art transmission techniques, such as load-modulation. It will be shown that the presented and future applications are not feasible with these transponder systems. Figure 1 shows a sensor-transponder system for medical applications. The reader is located outside of the body. It emits a magnetic field to provide power to the transponder. In state of the art transponder systems, load-modulation is used to transmit data from the transponder to the reader. Thereby a switchable resistor R is connected as a load to the resonant circuit L and C. In consequence, the idle current and further the magnetic field strength at the transponder can be changed. This change can be detected at the reader antenna by a receiver. In practice this change is relatively low compared to the field of the reader and noise.

In the presented application the transponder’s dimensions should allow catheter-implantation. Consequently, antennas with the shape of a stick and only a few millimeters in size are required. Transponders with additional sensors consume significantly more energy than simple ID-transponders. The maximum possible distance between the reader and the implanted transponder has to be considered, e.g. to make such a system suitable for corpulent patients. Data transmission has to be possible over the required distance and with the necessary data rate. To make a medical diagnosis reliable, the transmission has to contain information about the pressure progression of heart beats.
In transponder systems the so called energy range and data range can be distinguished. The energy range characterizes the maximum distance, where the transponder can be provided with enough energy to work. Whereas the read range characterizes the maximum distance, where the reader could receive the transponders data signal. Usually simple ID-transponder systems feature the disadvantage of a much smaller read range than the energy range. Nevertheless for this and similar future applications, the energy supply and data transmission have to be possible over distances of 40 cm at least. Nowadays there are no systems that meet these requirements.

Preliminary studies [4] have shown, that a sensor-transponder and its corresponding antenna with the required size, can be provided with enough energy at a maximum distance of 40 cm. Thereby optimized antennas were used. In consideration of the human body and antenna loss effects, a frequency was found where the best results could be achieved. The data transmission has to be realized under these conditions. In the next sections the limitations of conventional techniques will be discussed. It will be shown that with the given conditions, data transmission is not possible with existing techniques. This paper discloses a new transmission technique, that makes a data transmission possible at the required distance.

II. PROBLEM INVESTIGATION

The read range is limited by several factors: the magnetic coupling between the antennas is very low. This causes a small signal strength at the reader antenna. Hence, the sensitivity of the receiver limits the read range. Furthermore the voltage amplitude caused by the generator at the reader antenna is relatively high compared to the transponder signal. This makes signal processing difficult. Noise of the power amplifier is also much higher than the transponder signal. If the SNR (Signal to noise ratio) drops below a minimum, a decoding of the transponder signal is not possible. Moreover man-made noise and antenna movements disturb the data transmission as well. Detailed considerations will be given in the next sections.

A. Transfer function

The transfer function is needed to analyze the transmission channel. From it the expectable signal strength and channel characteristics can be obtained. In order to derive the transfer function the equivalent circuit shown in figure 2 is used. The variation of the voltage over the resonant circuit caused by the modulation resistor R can be modelled by a voltage source \( V_T \). The transmission channel itself is represented by a transformer equivalent circuit. Losses are represented by \( R_L \) and \( R_T \). The generator is represented by its inner resistance \( R_G \). The transfer function \( \frac{V_C}{V_T} \) can be obtained by solving the Kirchhoff’s mesh-law. The result is a first order band-pass function. The transfer function can be derived using the parameters determined in [4]. The parameters are \( L = 409 \, nH \), \( R = 9.8 \, m\Omega \), \( C = 1:1 \, nF \), \( R_T = 2.4 \, \Omega \). The result is shown in figure 3.

![Fig. 2. Equivalent circuit of the load-modulation transmission channel](image)

![Fig. 3. Evaluation of the transfer function](image)
By switching the load resistor $R$, an amplitude shift keying modulation is produced. In the frequency domain, upper and lower sidebands appear. The generator signal, transmitted from the reader to the transponder, acts as a carrier for data transmission in the opposite direction. A 13 kBit/s Manchester coded signal has baseband frequency components at 26 kHz. At the corresponding sideband frequencies, the transfer ratio is about $196 \cdot 10^{-6}$. In case of a modulation voltage of 1 V at the transponder side about 200 $\mu$V is reached at the reader antenna. In comparison to the sensitivity of common receivers that is about 1 $\mu$V, this value is high enough. Therefore, the sensitivity is no limitation here.

**B. Noise Sources**

Several noise sources exist in a transponder system. The transponder signal is disturbed by noise-voltages and -currents. The noise sources are in the frequency generator, the power amplifier, the antenna and in the receiver.

The power amplifier adds additional noise. This noise consists of shot noise caused by pn-junctions and Johnson-noise caused by resistors. Thereby the mean square voltage at the receiver is of interest. The mean square voltage produced by a conventional power amplifier (noise figure 16 dB) was measured as 2.3 mV. The gain of the parallel resonant antenna circuit causes an amplification of the noise near to the resonant frequency. The spectral noise density $V_{sd}$ is composed of voltage and current noise densities. Thereby the noise voltage of the source is multiplied with the system gain.

With the help of a spice simulation, the mean square noise voltage can be estimated. The result is shown in figure 4. A spectral shaping of the white noise input can be seen. The noise density is maximal near to the generator frequency. The mean square noise voltage can by obtained by integrating the noise density over the receivers frequency area. With a bandwidth of 100 kHz, which is necessary for a 13 kBit/s Manchester coded signal, a mean square noise voltage of 115 mV is reached. This value is several orders of magnitude higher than the transponder signal voltage, which is about 200 $\mu$V.

The noise of the antenna is only caused by the real part of the impedance and could be estimated by the following formula [7]:

$$E_{Ant} = \sqrt{4kTR} \Delta f \approx 2 \frac{nV}{\sqrt{Hz}}$$

with $k =$ Bolzmann constant, $T =$ absolute temperature and $R_{Ant} =$ real part of antenna impedance. With a receiver bandwidth of 100 kHz an effective noise voltage of 630 nV is reached. It could be said, that the power amplifier is the dominating noise source in the system and determines the SNR.

**C. Distortion**

Beside the unwanted noise, there are other disturbances that complicate the decoding of the transponder signal. A detuning of the reader antenna causes a displacement of the transfer function in the frequency domain. This detuning could be caused by changing the distance between the antennas. As can be seen in figure 3 the transfer function is shifted to higher frequencies in presence of a higher mutual inductance. Since the demodulation is done synchronous to the generator signal, the shift appears also in the baseband. In consequence the baseband transfer function is no longer a first order low pass. The transponder signal is distorted. This effect is noticeable by a overlaid oscillation of the transponder signal. The beat frequency correlates to the detuning.

If the transponder is implanted near to the heart, it will move in rhythm with the heart beat. The mutual inductance between the coils depends on the orientation of the coils to each other. Because of that, the voltage damping over the reader antenna will vary as well. This variation is appreciable in the basebandsignal as a beat.
D. Signal to Noise Ratio
The SNR is a measure that describes the quality of the signal. If conventional load-modulation is used, and considering a 40 cm distance, the SNR can be calculated as follows:

\[
SNR = 10 \log \left( \frac{V_{\text{eff}}}{V_{\text{noise}}} \right) = 10 \log \left( \frac{(141 \, \mu V)^2}{(115 \, mV)^2} \right) = -58.2 \, dB
\]

Thereby a manchester coded signal with 13 kBit/s is assumed. Usually a SNR of about +10 dB is needed to get an acceptable BER (bit error rate). Data transmission with conventional load-modulation is not possible here.

E. Limitations to Load-Modulation
Conventional load-modulation has several disadvantages that lead to a reduction of the read range. As described in the previous chapter, the SNR is too low for a data transmission at the required distance. The sideband signal produced by load-modulation has a spectral distance to the carrier signal equal to the data rate. As can be seen in figure 4 the spectral noise power increases in the proximity of the carrier signal. The small spectral distance of some kilohertz also makes filtering impossible. Amplitude variation of the carrier signal, caused by detuning or antenna movements, superposes the data signal irreversibly and increases decoding complexity. Moreover load-modulation wastes energy in the transponder. During the modulation phase the modulation resistor \( R \) is connected to the resonant circuit. The proposed frequency conversion technique in contrast, uses this energy to generate a transmission signal at a separate frequency instead. Figure 5 illustrates this technique. A sensor-transponder system designed according to this technique is shown. With the help of a separated antenna a field is generated (e.g. 13.56 MHz). This field is used to transmit energy to the transponder. This energy is stored in the resonant circuit of the transponder until the voltage amplitude over the resonant circuit has reached its maximum, thereafter no active power is needed anymore. Only a small part of the whole power is used to supply the transponder circuits. A special circuit enables the antenna to oscillate at another frequency. Consequently, a field with a separate frequency is generated. A field frequency of 10.7 MHz, where good filters are available, or an ISM-Band

III. NOVEL APPROACH
In the preceding section it was shown, that no existing data transmission technique complies with the requirements. Hence, a new transmission technique has to be found. An essential improvement could be done, if a transmission signal with an own freely selectable carrier frequency could be generated, and not affected by the envelope function of the transponder resonant circuit. Hence a frequency could be chosen were the spectral noise density of the power amplifier is low. Moreover, with a higher spectral distance to the carrier, filtering could easily be used to suppress the unwanted carrier. Furthermore it would be an advantage, if no additional energy were necessary to generate the transmission signal.

A. Frequency Conversion
The solution is a technique, from now on referred as frequency conversion. During the modulation phase at load-modulation technique, energy stored in the resonant circuit of the transponder is converted into heat by the modulation resistor. The proposed frequency conversion technique in contrast, uses this energy to generate a transmission signal at a separate frequency instead. Figure 5 illustrates this technique. A sensor-transponder system designed according to this technique is shown. With the help of a separated antenna a field is generated (e.g. 13.56 MHz). This field is used to transmit energy to the transponder. This energy is stored in the resonant circuit of the transponder until the voltage amplitude over the resonant circuit has reached its maximum, thereafter no active power is needed anymore. Only a small part of the whole power is used to supply the transponder circuits. A special circuit enables the antenna to oscillate at another frequency. Consequently, a field with a separate frequency is generated. A field frequency of 10.7 MHz, where good filters are available, or an ISM-Band

![Fig. 5. Transponder system with frequency conversion](image-url)
frequency could be chosen. The amount of energy transferred to the second frequency can be adapted to the requirements of data rate and energy consumption. The generated data signal could be received by a separated antenna, tuned to the corresponding frequency at the reader, by a gradient antenna [10], or by a novel antenna design developed for that purpose.

B. Comparison to Load-Modulation
By comparing with the load-modulation technique, the advantages of the new approach will become clear. For that purpose load-modulation and frequency conversion were tested under the same conditions.

Figure 6 shows the voltage over the transponder resonant circuit using load-modulation in frequency domain. The load-modulation implicates upper- and lower-sidebands in the spectrum. These sidebands are symmetrical around the carrier frequency generated by the reader, as shown in figure 6. At the reader side, the sidebands are under the noise floor.

The generated signal in frequency domain using frequency conversion is plotted in figure 7. A signal with an own carrier frequency of 10.7 MHz is generated.

C. Energy Balance
For energetic aspects two factors need to be considered: the generation efficiency of transmission signal as well as negative impact in the energy supply of the transponder chip. In frequency conversion the received energy is directly used in the antenna resonant circuit to generate a transmission signal. Hence, no energy is lost in rectifiers, amplifiers or any energy storage as happens in conventional techniques (cp. 8 (b)). Therefore this technique is very efficient as illustrated in figure 8.

D. Reachable Performance
Now the reachable performance is of interest in order to make a comparison to other possible solutions. With the help of the energy stored in the resonant circuit and the channel transfer function, the voltage at the receiver can be calculated. Between the transponder antenna and a receiver antenna there is a transfer ratio of about $3 \cdot 10^{-3}$, assuming an antenna tuned to...
10.7 MHz. The mean square value at the receiver is 2063 µV.
The mean square noise voltage can be calculated by integrating the spectral noise density from the spice simulation in figure 4. With a receiver input bandwidth of 300 kHz, which is necessary for such a signal, a mean square noise voltage of 1500 µV is reached. The SNR can be calculated:

\[ SNR = 10 \log \left( \frac{(2063 \mu V)^2}{(1500 \mu V)^2} \right) = +2.77 \text{ dB} \]

A value of 2.77 dB corresponds to an improvement of 60.97 dB compared to load-modulation technique (~58.2 dB). Together with a matched-filter a ratio of about +17.77 dB is possible. This value is over the minimum of +10 dB and leads consequently to an acceptable BER.

**IV. EXPERIMENTAL EXAMINATION**

An experimental measurement shall show, that frequency conversion techniques enables data transmission from a deeply implanted sensor-transponder. To create a substitute that simulates the electric properties of the human body, a phantom substance was prepared. A test transponder was realized with an analogue frontend working with frequency conversion. In the reader a software defined radio shown in figure 9 was used to receive the transponder signal. The receiver consists of an analogue band-pass filter, an ADC, a mixer and a matched-filter. The main goal of the experiment is to measure the achievable SNR after the mixer over the distance.

In the next section the achievable SNR will be measured.

**A. Reading Range**

To evaluate the new technique, the achievable signal strength at the receiver and corresponding SNRs were measured. The distance between the reader and the transponder was variated between 8 cm and 46 cm. Figure 10 shows the measurement results: as mentioned before, a minimum SNR of +10 dB is necessary to get an acceptable BER. Considering a matched-filter with 15 dB signal to noise improvement, a SNR of -5 dB at the input of the receiver is required. The measured SNR is higher in up to 45 cm distance. The energy range is about 40 cm. Therefore, the maximum possible read range is reached.

**V. CONCLUSION**

Data transmission for deeply implanted sensor-transponders has been analyzed. It was shown, that data transmission over the required distance is not possible with conventional solutions. A new data transmission technique called “frequency conversion” that makes a maximum read range possible, was presented. A practical implementation and measurements have verified the feasibility of this technique.
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1 Introduction
Nowadays our markets are full of goods from every corner of the world. Not only has the shipment of these goods increased over the last years, but storing them has also become a more and more challenging necessity. Furthermore, every larger company needs warehouses to store raw materials and components during the manufacturing process of their final products.

The main part of a warehouse consists of many high-bay racks. Between these racks, forklifts move through narrow aisles at high speeds, storing and retrieving the goods. Every shelf is supported by pillars. If any of these upright posts get damaged, e.g. by a crash with a forklift, the whole shelf is destabilized and may collapse. This is not only a safety risk for the workers, but may also lead to financial losses as a company relies on the immediate availability of its stored goods.

During the last years, a standard has been developed to minimize the risk of such collapsing high-bay racking. However, the damage control still has to be performed manually. Usually, an inspection of all shelves has to be done once a week. In a worst case scenario, a critical crash can occur directly after the inspection without being reported for an entire week. Therefore, a fully automated system which detects crashes with rack pillars can improve safety, avoid accidents and remove the human factor from the pillar check.

2 Hardware demands
A monitoring system for high bay racking requires the use of electronic devices at every column of the shelves. A normal warehouse has racks with up to several thousand pillars, which have to be monitored individually with respect to external shocks. Every pillar is protected by a special elastic bumper that mitigates damage caused by crashes with forklifts or other vehicles.

Within the bumper, a wireless electronic device monitors the pressure and sends a radio signal when a pressure change occurs. Depending on the pressure difference, an incident is categorized from a light impact with no harm for the shelves to a harsh impact requiring immediate action by the warehouse staff. To guarantee a high operating time between battery changes, such a device needs to be highly energy efficient.

When a pressure difference is detected, the device emits a radio signal that is received by a repeater unit. The repeater manages up to 100 sensor nodes and makes sure radio messages are passed to a main control unit. If the repeater is located too far away from the control unit, messages are routed through repeaters located closer to the main unit.
The main unit receives every crash incident within the warehouse and visualizes the collected data on its display. All data is transmitted using the UHF ISM frequency band. This band is free to use without licensing costs and limited only in the maximum channel power and channel bandwidth.

The main unit is also used for short-range configuration of the radio nodes when bringing the system to service. Therefore, a low frequency wake-up impulse is sent to activate any node within a range of approximately 50 cm.

3 Software demands

The system can be described as a large network of radio nodes sharing a frequency band with limited range and bandwidth. Additionally, this network needs to be highly energy efficient so that long operating times between battery changes can be realized. Therefore, a customized protocol is designed to fulfill these requirements and make sure no critical impact is missed and the warehouse manager is informed within seconds after a crash event.

To realize the goal of energy efficiency, the system uses static routing. This means the routes from the radio nodes at the rack posts to the handheld unit located in the warehouse manager’s office are planned before bringing the system to service. Planning the network means assigning up to 100 sensor nodes to a repeater. The repeater itself is either assigned to a repeater located closer to the main control unit or to the main control unit directly.

Every crash incident is sent from the radio node at the rack post to the assigned repeater via a bidirectional protocol, i.e. the receiving unit acknowledges the received data to the sender. If there is no acknowledgement from the receiver, the data is resent until it has reached its destination.

Once per day, every sensor node sends a lifesign message containing the current battery voltage. These lifesigns are used to detect malfunction and low battery power. If the system detects a need for maintenance, alarm messages are displayed at the main unit.
4 System performance and conclusion

The system itself has to be reliable due to its safety functions. Therefore different states of the sensor nodes need to be detected by the system, e.g. low battery state of a radio node, repeater malfunctions or radio nodes which cannot send a lifesign or crash events to a repeater.

Several measures are implemented to avoid those critical states. The current battery voltage of all radio nodes is monitored in certain time intervals and the warehouse staff is informed in case of a low battery state.

Furthermore, all communication paths among the repeaters are checked in short time intervals and errors are detected swiftly. If an interruption of the predefined routing path occurs (e.g. because of a power failure), the repeaters store the radio messages received from the sensors and re-send them as soon as correct operation is restored. This minimizes the risk of data loss.

The safety of high-bay racks is improved by using sensor nodes within special bumpers. Critical impacts are reported in seconds and the warehouse staff is warned. Not only the safety risks are minimized, but also any person or company responsible for the crash can be tracked due to a fast system response.

This project was founded by "Arbeitsgemeinschaft industrieller Forschungsvereinigungen »Otto von Guericke« e.V.".
Abstract
People in Germany live longer than ever. The demographic change is no longer a future vision but rather pervasive in nowadays society. The attempt to extend the lifetime of individuals represents an enormous challenge for the health system. Caught in the dilemma of steadily rising costs and the continuing demand for a best possible health care, new ways of providing health services are essential. The MeDiNa project addresses this problem and develops both technical and organizational solutions for home-care of cardiac patients. The aim is to allow a periodically monitoring of health status of people in their own home and thus to detect recidivisms at an early stage and to initiate appropriate countermeasures. As a result, there are benefits for both the patient and the health system.

Introduction
The desire of having a long and fulfilling life is everyone’s wish. Everyone will already have felt at least once the demand to get well and to regain the usual productivity as soon as possible. As with many other health problems, also in the case of cardiac diseases, this demand is met by the offer of a multi-week stay in a rehabilitation clinic. However, the duration of this stays decreases for years. For example, the average stay for all types of rehabilitation in NRW was 32.4 days in 1990 and 27.7 days in 2007 [1]. The length of stay for cardiac rehabilitation was actually of only 21.9 days [1]. Despite the improved treatment methods and modern clinical devices, a complete recovery of patients in this short time is not always possible. Rather, patients are released earlier to the ambulant sector. As a consequence, the usually elderly patients continue rehabilitation in their own home without being periodically monitored in short intervals by medical and nursing staff. This issue is addressed by the research project MeDiNa, promoted by the German Federal Ministry of Education and Research. (Mikrosystemtechnik für ganzheitliche telemedizinische Dienstleistungen in der häuslichen Nachsorge; grant number: 01FC08056).

Cardiovascular diseases cause of death no. 1 in Germany
Cardiovascular diseases are the leading causes of death in Germany and Europe. In 2007 a total number of 419 723 people died in Germany due to diseases of the circulatory system and heart attack [2]. In Europe, the statistic counts nearly 4.5 million deaths annually [3]. The estimation of medical authorities, that the number of new cases in the near future will continue to increase, is particularly disillusioning [3]. Therefore, the focus is on providing the best treatment of the occurring diseases. This depends on several factors: early diagnosis, rapid and efficient treatment and comprehensive rehabilitation. For the latter to continue effectively after the in-patient rehabilitation, with strong partners from industry and regional health service providers, the consortium of Fraunhofer Institut für Mikroelektronische Schaltungen und Systeme, Universitätsklinikum Aachen, MUL Services GmbH, Forschungsinstitut für Rationalisierung (FIR) e.V. an der RWTH Aachen, Institut für Arbeitswissenschaft (IAW) an der RWTH Aachen and Philips GmbH (Unternehmensbereich Healthcare) develops a holistic approach to microsystem technology supported home-care of rehabilitation patients (see Figure 1).

Lack of periodically monitoring after rehabilitation is a problem
After discharge from the rehabilitation clinic, regular visits and intensive contacts with medical staff are a thing of the past. This lack of periodically monitoring of patients, shortly after a cardiac disease, constitutes a big problem for the patients and the health system. Deterioration of the state of health will be recognized too late or not at all which may lead to complications and serious health damage. For example 80 % of the annually 300,000 new cases of heart attacks occur at home. Of these 80 %, 50 % remain unnoticed [4]. In addition
to the partly dramatic consequences for the patient, this fact has an enormous impact for the health system. Relapses in the in-patient treatment or complications come with the result of much more expensive medical treatments. In this way, heart diseases including frequent re-hospitalization, are the cause for expenses of nearly 170 billion € in the EU [3]. Many of these cases and consequently their expenses can be avoided by early diagnostics and be treated with lower impact for both, the patient and the health system.

Telemedicine solutions show new ways in health care

Recent telemedicine approaches offer, in association with modern sensors, possibilities to capture the necessary information of high risk patients in a quick and inexpensive manner, process it comprehensively and make it available centrally. Thereby the decoupling of the medical examination from the availability of medical personnel offers enormous potentials for health care. Thus, for example, the so-called tele-monitoring through a computerized monitoring system, checks the vital
signs (pulse, blood pressure) which are sent immediately to a provider (medical practice, rehabilitation station) where the qualified personnel can intervene directly in case of irregularities. Most telemedicine applications tend nowadays to a faster, better and wider communication of patient data via electronic ways (tele-consultation). Although the technological basis for telemedicine services appears to be available, it lacks so far on the sustainable concepts of integration of the telemedicine in the first health care market. This shall be achieved with the MeDiNa’s developed business model for the provider of such services (Medical Service Provider).

The aim of MeDiNa project is to make use of the telemedicine potential and to allow a simple and continuous monitoring of patient data by the rehabilitation experts (doctors, caretakers and therapists). Based on this data the experts will be enabled to readjust and reorganize therapies and to intervene earlier in cases of emergency. This is the basis for providing modern telemedical services (for example electronic visits) for the aftercare of cardiac patients. In order to test this approach in a prototype and to validate the usefulness by means of a patient study there are two technical components necessary which are being developed within the project (see Figure 2):

- MeDiNa-HomeBox for the acquisition of vital parameters of rehabilitation patients in their home environment
- MeDiNa-Portal for the conditioned presentation of vital parameters for doctors and for the ensuring of data security through a comprehensive rights and role model.

Innovative use of technology
The MeDiNa-HomeBox comprises of various wireless coupled sensors for the regular supervision and monitoring of vital parameters without a direct involvement of medical staff. For this purpose the patient will be fit with a MeDiNa-HomeBox for the domestic use. Besides the acquisition of basic medical data such as ECG, blood pressure, body temperature, weight and respiratory rate, specific measurements are added depending on disease and clinical history in order to reflect and track the situation of the patient. The goal is the intelligent integration of existing applications to a holistic service system. Due to the primarily elderly patients special emphasis is put on the usability of the system. This aspect is supported for example by using a touch-screen display. In addition the patient must remain extensively uninfluenced due to the use of the MeDiNa-HomeBox. By using microsystem technology, these requirements will be satisfied.

After the acquisition of the vital parameters, these data will be sent to the MeDiNa-Portal via UMTS and GPRS respectively. If no mobile connection could be established, the data exchange can be realized over a standard telephone line. The portal supports the communication between all parties involved (e.g. patient, hospital) and the coordination of the service contribution. For the implementation of the desired system solution, portals offer different suitable functions and technologies. As important basic functions can be mentioned among others: user management, authentification, searching, personalisation, role and right administration and data security.

Thus the parameters captured by the different sensors are evaluated in detail after the transmission to the portal and prepared adequately and structured for the targeted group and
made available to authorized persons or institutions. Special aspects thereby are the unification of different user needs, an efficient supply of information and data between the different parties as well as high security and data protection against the background of handling sensitive personal data.

Efficient information logistics
The technical components MeDiNa Homebox and MeDiNa Portal form the basis for providing telemedicine services. In the center stands the so-called Medical Service Provider (short: MSP). The focus off MSP’s activities concentrates on ensuring an efficient information logistics, the correct information, at the right time, in the correct form and at the correct place. Concretely, this means that the data for the diagnosis, measured by the sensor system, unaltered by the transmission, prepared adequately for the addressee had to be delivered in real time to the physicians or nurses. The system also must permit a flow of information between the medical personnel and from the medical personnel to the patients. In summary the MSP must be able to arrange suitable systems and information services based on technology potentials and medical requirements. Apart from the primary and already outlined services, as collection of the vital parameters, monitoring and configuration of the state of health or the rehabilitation plan respectively as well as providing the underlying data and information management, value added services can be offered and used by the patients.

Examples are:
- Service for monitoring the medication: It can be recognized in time, if the patient must reorder his medicines or if the storage life of a medicine expires.
- Service for monitoring the fitness activity: Here the daily sportive activity under observation of the vital parameters could be reconstructed.
- Service for monitoring the diet: An intelligent calorie computer could compute the calories connected with the meal and make proposals for further meals.

Based on the integration of different technologies and the development of services for the Medical Service Provider, a holistic approach can be developed to the micro-system supported providing of services.

Result
For about 4 million cardiac risk patients in Germany the MeDiNa system offers an effortless, short interval control of relevant vital parameters in their domestic environment [4]. Even with longer treatment intervals, the continuous monitoring of vital parameters makes an exact controlling of the therapy possible, and contributes to the improvement of the compliance and disease condition of the heart patient. Thereby the patient’s quality of life increases and the annual costs for the support can be reduced by reduction of hospitalizations, emergency treatments and physician visits[5]. Thus, for example, the telemedicine study “Herzensgut” of the insurance company “Kaufmännische Krankenkasse Hannover” pointed out that the utilisation of telemedicine equipment results in a cost reduction of around 20% (on the average about approximately 1,400 €)[6]. Fast and purposeful presentation of information about pre-existing conditions, examinations and therapies is a further result of the digital data acquisition and forwarding. Thus the project addresses two central problems. On the one hand, a better health welfare service for patients is made possible, and on the other hand, ways are pointed out, how the health economy can increase the treatment quality in the next years, despite foreseeable financial restrictions. An improvement for both sides.
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Aktualisierungsdatum: Oktober 2008


Motivation and Brief Description

Hospitals in North Rhine-Westphalia will face considerable challenges in the years to come, particularly the conflicting objectives of improving both the cost situation and the quality of the performed efficiency. The aim is to remain or to become competitive and to be one of the Hospitals of the Future.

Here, the technical areas of hospitals are starting points for optimization, increase in efficiency and cost reduction. These areas include, for instance, hospital IT, energy supply or building services engineering and maintenance, as well as hospital logistics and facility management.

Innovation and optimization in those special areas usually result only in partial cost reduction and quality increase and disregard optimization in the overall technical system of a hospital. Optimization potential of an overall approach is, thus, given away, which may even result in conflicting goals by means of negative effects of measures in one area on other areas. Often, valid technical and performance figures of special areas to evaluate individual measures do not exist. Therefore, cross functional concepts and tools are entirely absent.

Hospital Engineering aims to close this gap. It hopes to benefit from an overall approach to the technical system of a hospital by researching current innovation and particularly its effects on adjacent areas, the development of best-practice solutions, the optimization of the overall system and the characterization with the help of significant key figures. Practical implementation eventually follows in so called “thematic projects”. Thus, Hospital Engineering reaches far beyond classical approaches to hospital technology and provides a foundation for a competitive and technically sustainable hospital.

As part of the competition Med in.NRW, Hospital Engineering is a government-funded project by the state of North Rhine-Westphalia. A total of 235 contributions and up to 70 million Euro from EU-, state- and commune-funds, as well as from private partners account for Med in.NRW to be the grandest competition of the regional government as part of the NRW-EU-Ziel2-Programms. The ETN Forschungszentrum Jülich GmbH is in charge of the project.

Participation of Fraunhofer IMS in Hospital Engineering

Fraunhofer IMS designs and constructs a suitable and realistic laboratory for the required room systems at the Fraunhofer-inHaus-Center. The following rooms of a hospital will be constructed including all furnishing and technical infrastructure: reception and waiting area, nurses’ room, patient’s room including bathroom, treatment room, room for fitness and physiotherapy, operating area, storage and hallway.

Fraunhofer IMS is responsible for the project Staff- and Patient-Assistant. This project aims to enhance patient-autonomy with the help of assistant systems and to increase staff-assistance via sensor-supported acquisition of context data and system solutions. As part of this project, the focus is on the following:

Hygiene-related System Solution

The issue of hygiene becomes increasingly important in German hospitals. According to estimates by the Deutsche Gesellschaft für Krankenhaushygiene (DGKH, German Society for Hospital Hygiene) in 2009 40,000 fatalities were results of infections in hospitals. Particularly the increase of resistant
germs (e.g. MRSA\(^1\)) is of major importance. Fraunhofer IMS explores and develops solutions for the realization and documentation of hygiene processes with the help of sensor-supported devices for hand disinfection.

**Software for Behavioral Analysis**

By means of a software solution and the integration of sensors in the patient's room and the instruments and furniture inside, the patient's behavior and care is recorded. This aims to detect abnormal behavior or dangerous situations in time and to develop automatic care documentation. The overall concept includes the transmission of collected data to an existing emergency call system and to the KIS\(^2\).

**Mobile Ward Round/Care Assistant Vehicle**

A constant access – independent from time and place – to KIS-data and other medical subsystems in the form of digital case files is indispensable for medical staff. Particularly during ward rounds, all data needs to be accessible at the patient's bed. Fraunhofer IMS explores and develops efficient solutions for data-display, -entry and -transmission in case of mobile ward rounds or care assistant vehicles.

**Fitness, Exercises of Precautionary Measures and Rehabilitation**

Fraunhofer IMS explores and develops ways to integrate fitness machines into existing IT-systems and hospital-processes in the context of precautionary measures and rehabilitation. In particular, Fraunhofer IMS is engaged in the development of new intuitive control concepts and the networking of fitness machines and medical system solutions, for instance, to enable automatic transmission of performance data to the KIS, the family doctor or physical therapists. The other way around, a software solution is to be developed, which proposes a fitness program for the patient based on his or her current physical condition.

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\(^1\) MRSA: methicillin-resistant *Stapylococcus aureus*

\(^2\) KIS: Krankenhaus-Informationssystem

(trans. Hospital Information System)
As part of the project *JUTTA – Just in Time Assistance*, funded by the German Federal Ministry of Education and Research, Fraunhofer IMS, in cooperation with industrial partners and a nursing service in Duisburg, develops new methods of resolution and business models for care which meet the demand of people in need of assistance in the privacy of their home. This new model envisions care according to actual need of assistance instead of predetermined and fixed tours of care staff. This aims to preserve and enhance the individual competence of those in need of care to allow a predominantly self-determined life even later in life.

The actual need is visualized by means of a signal light as the interface of care and technology. Similar to a traffic light, different colors indicate the current state of the person taken care of: red displays an urgent need of care, yellow suggests that assistance is useful and green announces a currently self-determined life.

The actual care process is then carried out by family members, voluntary helpers, professional care staff or – in case of an emergency – by doctors. To ensure the medical attendance in the privacy of the patient’s home, medical engineering sensors are employed additionally in order to transmit measured data to a medical center. The medical center then reacts in case of an emergency.

As a technological base for the signal light, sensors and actuators using radio technology are installed in the apartment. Therefore, standard components of building service engineering like motion detectors, light switches, window or door contacts, which are networked, are employed. All sensor information and data is evaluated at the apartment, so that all information concerning detailed patterns of behavior remains there. First, the system gets to know the patient’s usual behavior and configures itself accordingly. In case of unusual occurrences, the nursing staff is informed by means of the signal light.
The signal light is displayed at the nursing service’s coordinating unit where the nursing staff’s tours are organized according to the actual needs of the patients. Therefore, care assistant vehicles are equipped with GPS, so that the coordinating unit knows the position of the vehicles at all times. In order to support and facilitate documentation, care staff is in possession of a mobile unit to record care processes in a simple and quick way.

The JUTTA-system is currently employed in real to life living environments to gain first experiences in the field of dynamic care processes. In the long run, service according to individual needs is aimed to allow a convenient, self-determined and secure life in the privacy of one’s home later in life.

(For further information, please visit www.just-in-time-assistance.de)
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6. Theses

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Eschke, J.:
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Entwicklung eines energieeffizienten Basisbandprozessors für passive UHF RFID-Transponder.
6.4 Bachelor Theses


6.5 Project Theses


7. Product Information Sheets

Betriebsstundenzähler für Baumaschinen
IMS-Duisburg, 2010

Business field micromachined pressure sensor technology
IMS-Duisburg, 2010

CMOS image sensor with 118db linear dynamic input range
IMS-Duisburg, 2010

CMOS linear photosensor array, 1 x 512 pixel
IMS-Duisburg, 2010

CMOS ToF-Sensor for 3D imaging, 64 x 8 pixel
IMS-Duisburg, 2010
Distributed test system for interoperability tests  
IMS-Duisburg, 2010

Drahtlose Sensornetze in der Land- und Forstwirtschaft  
IMS-Duisburg, 2010

Drahtlose Temperatur-Überwachung in der Frischelogistik  
IMS-Duisburg, 2010

Drahtloses Messen – Bsp. Fahrrad-Computer  
IMS-Duisburg, 2010

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IMS-Duisburg, 2010

High temperature capacitive pressure sensor  
IMS-Duisburg, 2010

High-temperature IC’S  
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IMS-Duisburg, 2010

Ihre Idee – Wir setzen sie um  
IMS-Duisburg, 2010

IMS LS-3580 CMOS linear photosensor array,  
1 x 3580 pixel  
IMS-Duisburg, 2010

Integrated capacitive pressure sensors  
IMS-Duisburg, 2010

Integrated solutions for bioelectronic sensing  
IMS-Duisburg, 2010

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IMS-Duisburg, 2010

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IMS-Duisburg, 2010

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Wireless sensor networks  
IMS-Duisburg, 2010
# Chronicle

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INHAUS-CENTER EVENTS 2010

In 2010, Fraunhofer-inHaus-Center hosted many events for professional audiences. Highlights include the following:

**June 24, 2010: win² – Technical Modernization of Real Estate – Solutions and Potential Benefits**

More than forty percent of the world’s energy consumption is related to buildings. This is why technical modernization of residential and commercial properties has a great potential for economic development and the creation of workplaces, as well as for energy saving and environmental protection. The outdated technical equipment of the majority of buildings accounts for great optimization potential. Rapidly changing user needs and usage requirements demand suitable solutions: This includes, for example, the enhancement of the structural and functional flexibility of rooms and buildings. Fraunhofer-inHaus-Center and the Niederrheinische Industrie- und Handelskammer (Chamber of Commerce and Industry of the Lower Rhine region) took up this current debate and organized the win²-event “Technical Modernization of Real Estate”. In the course of three hours, various experts provided information about the current conditions of the field of real estate for 45 participants. Furthermore, diverse concepts of modernization in combination with cost-benefit assessment were presented. The evening closed in a lively discussion and a relaxed get-together.


Today, the field of healthcare and social welfare faces diverse challenges: The cost pressure for providers of medical service increases, while the population experiences demographic changes, which will result in a rising number of elderly in need of care in the future. At the same time, there is no additional care and medical staff at hands; quite contrary, the number has been decreasing. Which solutions are then necessary to develop a sustainable and innovative healthcare and social sector?

This year’s Fraunhofer-inHaus-Forum tried to find answers to this question. 160 participants listened to lectures researchers of each business area had prepared with special reference to the field of healthcare. Keynotes by well-known representatives of the field framed the event. The day ended in a panel discussion of leading experts.

As it has become common to the establishment of the inHaus-Forum, visitors had the chance to take a look at the inHaus-partner’s exhibitions and the laboratories.
WORKSHOP ON ENERGY SELF-SUFFICIENT SENSOR NETWORKS

The Fraunhofer one-day-workshop on energy self-sufficient sensor networks on November 16, 2010, Munich, provided numerous hands-on examples from different branches and was geared to experts from development and manufacturing as well as quality control and reliability. Fraunhofer IMS presented current developments in integrated low-power sensors and in collaborative signal and information processing. The workshop was preceded by the Fraunhofer-Forum »Aufmerksam im Schwarm – Energieautarke Sensoren und Sensornetze« on November 15 at Fraunhofer-Haus.
VISION 2010

As in the years before Fraunhofer IMS took place in the VISION 2010 fair in Stuttgart from November 9th to 11th 2010. Fraunhofer IMS presented its news in the field of 3D CMOS image sensor technology working on the time-of-flight principle and infrared sensor technology.

Special interest was given to the infrared sensors which provide a better level of safety for drivers. Objects at roughly body temperature are luminous in the infrared region at a wavelength of around ten micrometers. Detectors in the camera register this thermal radiation and locate the source of heat. This enables drivers to see people or animals long before they come into vision through dipped headlights. Another advantage: Other road users are not inconvenienced by the invisible infrared radiation.

Journalists were especially interested in these research results and, as a result, these news were presented on the first page of the fair newspaper.

A few words about the fair:

The VISION is an international trade fair for industrial image processing and identification technologies. It is the meeting place of all players this sector and therefore the most important marketing tool in order to meet international customers and to present to them the latest developments in image processing.

Approximately 6,800 visitors from over 50 countries, predominantly from Europe but also from overseas, mainly from the USA and South Korea, came to Stuttgart this year to obtain information at the world trade fair for machine vision.

ELECTRONICA 2010 IN MUNIC

The Electronica Fair in Munich counts among the biggest trade fairs worldwide and presents concentrated expert knowledge in nearly all consumer segments and user industries – from automotive and industrial electronics to embedded, wireless, medical electronics and MEMS.

It is the meeting place for decision-makers who search for attractive offers and for good products to meet current and future requirements.

Fraunhofer IMS presented the following topics:
• Innovative computer process control for micro reactors in the chemical industry
• High Temperature ASICs and processes for applications up to 250 degree
• Vacuum isolation panels with integrated low power pressure sensor ASIC and wireless communication
• Medical implants with integrated low power pressure and temperature ASIC and wireless communication
• Image Sensors for high demands (aerospace 3D imagesensors)

All in all the fair was a big success.
From November 4th to 6th 2010 the Fraunhofer-Talent-School took place at IMS.

Setting up radio circuits, learning to understand the construction of microchips and the design and simulation of a chip at the computer – these tasks were a cool challenge for the participants of the Duisburger Fraunhofer-Talent-School 2010.

33 interested teenagers from whole Germany, but predominantly from North-Rhine Westphalia, met on November 4th at the Fraunhofer IMS Talent-School to experience the microelectronic working environments of engineers and scientists and to get useful incentives for their own career.

The Workshop 1 “Mit uns funkt’s – Vom Schwingkreis zur Funkanwendung” (“… – From the oscillating circuit to the radio application”) focussed on constructing microcontroller circuits and to start running them. The teenagers for example brazed devices on circuit boards.

During Workshop 2 “Chips und mehr” (“Chips and more”) the participants got a taste of the fascinating world of microelectronics. The clean room and laboratory tours pointed up the complexity of chip design. The participants worked practically with chips, oscilloscopes and microprocessors.

In Workshop 3 “Rechnergestützter Schaltungsentwurf – Wie kommt die Schaltung auf den Chip?” (“Computer-aided circuit design – How do circuit and chip meet?”) the teenagers learned about different design processes and the corresponding CAE-Software. On the basis of a small specimen circuit, the participants independently sampled the design of a circuit. After some failed attempts, they had an error-free working circuit.

Well, no one is born a master!
WORKSHOP: RELIABILITY OF SEMICONDUCTOR DEVICES

On March 18th 2010 the Workshop on the reliability of semiconductor devices took place in the Fraunhofer-inHaus-Center in Duisburg. This workshop was organised in cooperation with the GMM (Gesellschaft für Mikroelektronik) and around 50 participants from industry took part.

Microelectronics expands more and more into sensitive areas in which malfunctions can cause large material damage or even negative effects on health, for example in medical and automotive engineering. In automotive engineering the development ranges from comfort electronics, driver assistance and tasks in the power train to topics like “Drive by Wire”.

In addition, the requirements of the rough ambience in automobiles (temperature change, humidity, impurities) have to be considered. In medical engineering implantable systems, which do not only measure but also act e.g. by pharmaceutical dosage in the combat against diabetes, are developed. Therefore, microelectronic systems have to meet high reliability requirements. Especially the automotive industry expedites this topic. Furthermore, a particular reliability is required for space technology and military applications. The small quantities required for these areas pose a special challenge. Also in industrial electronics with its rough ambient conditions the devices are subjected to special reliability requirements.
Fraunhofer Institut IMS – einzigartige Innovationswerkstatt

GiW Duisburg Winter 2010

Ans Wissenschaft & Forschung

Funksignale aus dem Herzen

Herzklappenbein-Beinnahme mittels implantiertem Sensor

Die Technologie IMS des Fraunhofer-Instituts für Mikroelektronische Schaltungen und Systeme (IMS) entwickelt einzigartige Sensorsysteme, deren Einsatz implantiert wird.


Sehr klein gebaute Drucksensoren übertragen Messwerte drähtlos

Management & Aktuelles 2010

Repress Review

Praxis Physiotherapie April 2010

GFW Duisburg Winter 2010

Implantierbares Monitoring-System für Hypertoniker


IbS Januar 2010

Häufige Krankheiten und Erkrankungen

Diabetiker müssen eine spezielle Diätaufnahme bevorzugen, um die Herz-Kreislauf-Systeme einzuweisen.

Management & Aktuelles 2010
Dem Mattenbruch auf der Spur

New sensor monitors salt penetration in concrete

RFID in Wartung und Instandhaltung

RFID-Datenpools funkeln durch Metall

ISS Mai 2010

Polyscope August 2010

Materials Performance August 2010
Infrared camera provides a better view

Infrared cameras see more than the naked eye and can make road safety visible. Cameras for the long-wave infrared range have the disadvantage that the sensor requires constant cooling, which adds to the cost and complexity of the device. Now a new type of detector has been developed which functions at room temperature.

At night or in cool weather, the scene in our vision is often not what it seems and we can not see what's there. To make things worse, it is dark. The car ahead can be perfectly in our lane and we still can not see the deer on the road until it is too late. An emergency stop prevents a collision with the animal just in time. In such situations infrared cameras could provide a better level of safety. Objects at roughly body temperature are luminous in the infrared region at a wavelength of around one micron. Detectors in the camera register this thermal radiation and locate the source of heat. This could enable drivers to see people or animals long before they notice them through their headlight. Objects would not be accompanied by the invisible infrared radiation. The problem is that infrared cameras for the wavelength range above five microns like it cool – the sensor has to be constantly cooled down to about minus 79 degrees Celsius. Uncooled imagers for the long-wave infrared range do already exist today, but they are only available in the military sphere and are more or less unaffordable on the European market. This is now set to change. Researchers at the Fraunhofer Institute for Material Research and System Analysis IMPS in Düsseldorf have just announced a breakthrough: they have created a new type of camera.

“Light the fire in Germany to pump the technology”, says Dr. Dirk Weiskopf, a spokesperson for the RHEINISCHE POST: “The technology could be linked to automatic braking systems that stop the car when a person or animal leaves the main road, or a “hazard zone” style head-up display that shows other invisible objects to the driver’s screen.”

The new cameras are suitable for everyday cars since they work at room temperature. These cameras that work in the long-wave infrared spectrum are the ones that objects appear in, the humans and animals tend to be constantly kept cool, around 80 Kelvin (89K or 159°F). This is particularly difficult and expensive to do in road vehicles.

Room temperature infrared cameras do exist, but the technology is typically held for the US military and almost impossible to get in Europe. However, a German research group, the Fraunhofer Institute for Material Research and System Analysis IMPS, has created a room-temperature sensor, the infrared Focus Plane Array (FPA) that will be made available in 2010.

Infrared “Night Vision” Cameras Could Wake Up, Driving Safer

Infrared image taken by the Fraunhofer researchers.

Durchblick auch in der Nacht

Am Duisburger Fraunhofer Institut wurde ein neuerlicher bildgebender Sensor für den Infrarotbereich entwickelt, der im Gegensatz zu alten Geräten auch ohne Kühlung auf minus 99 Grad Celsius funktioniert.


Farbsensoren für bessere Sicht


Auf extreme Temperaturen vorbereitet

Bildsensoren, die zur Qualitätskontrolle in der Produktionstechnik für elektronische Bauelemente in höheren Temperaturen eingesetzt werden, müssen mit einer extremen Temperaturauslastung gerechnet werden können. Deshalb entwickelt man senso-
ren, die auch bei extremen Temperaturen arbeiten. Die Fraunhofer-Institute entwickeln derzeit ein System, das es ermöglicht, Bildsensoren zu entwickeln, die auch bei extremen Temperaturen stabil arbeiten.

Durch den Einsatz von ultrahochleistungs- bauelementen und einem speziellen Prozessdesign kann erreicht werden, dass die Bildsensoren auch bei extremen Temperaturen stabil arbeiten. Die Fraunhofer-Institute entwickeln derzeit ein System, das es ermöglicht, Bildsensoren zu entwickeln, die auch bei extremen Temperaturen stabil arbeiten.

Researchers develop image sensor for rough environments

Christian Hennschneidt

For automotive applications requiring very low and very high ambient temperatures, researchers from the Fraunhofer Institute for Microelectronic Systems (Duisburg, Germany) have developed a CMOS image sensor capable of working at an extended temperature range from -40 to 115 degrees Celsius.

Wide-angle image sensors based on CMOS technology (Charge-Coupled Devices) are operational at ambient temperatures of up to 60 degrees Celsius. The Fraunhofer Institute researchers state that they have developed a pixel architecture featuring an extremely low dark current. This radical current drop allows an extremely wide range of temperature increases, enabling image acquisition and reducing the available dynamic range of the devices. The reduction of this current, which freezes even in complete darkness, enables possible to capture very high quality images even in extreme heat, said Fraunhofer researcher Werner Breitenecker.

The CMOS based image sensor developed by Fraunhofer features a dynamic range on exposure fields of 0.9-9.9, resulting in high contrast and optimized detail reproduction in shadow as well as in very bright segments of the image. Its very high sensitivity and low noise makes the device suited for night vision gear, the researchers claim.

The device was developed within a customer project with a somewhat unusual specification. Despite the large area, the sensor features a resolution of only 256 by 256 pixels. "It was a customer-specific design," said Breitenecker. "The excellent signal-to-noise ratios of the device have been made possible by the relatively large pixels in combination with a very high signal-to-noise ratio."

Important for the CMOS-Bildsensor is the high pixel density on the chip. The high pixel density of the CMOS chip makes the device suitable for applications requiring high-resolution images. The sensor is capable of capturing images even in low-light conditions, which makes it ideal for night vision applications.

EE Times Oktober 2010

Markt und Technik Oktober 2010

Fraunhofer IMS Annual Report 2010
Ein Haus denkt mit - innovative Technik für das Wohnen von morgen


Das Haus von morgen ist kundengerecht. Es erkennt, analysiert und reagiert auf die Bedürfnisse seiner Bewohner. Mit einer Vielfalt von Technologien wird es die Lebensqualität aller Betroffenen verbessern. Das Ziel ist es, eine Lebenswelt zu schaffen, die sich an die individuellen Bedürfnisse und Wünsche von Menschen anpasst.

**Überblick über die Technologien**

- **Intelligente Gebäudesteuerung**
  - Automatisierung von Gebäuden, um Energieeffizienz und Sicherheit zu erhöhen
- **Geräteintegration**
  - Komfort und Sicherheit durch die Verbindung von Technologien
- **Personen- und Raumnutzungssensorik**
  - Erkennen und Reagieren auf Bewegung und Anwesenheit
- **Healthcare Services**
  - Konsultationen mit medizinischen Experten

**Das AAL-Magazin Februar 2010**

Das AAL-Magazin Februar 2010 bietet einen Überblick über die berühmten Institute für Mikroelektronik und zeigt, wie die Technologie den Lebensstil der Menschen verbessert. Die erste Ausgabe des Magazins behandelt die Themen, die für die Zukunft wichtiger werden werden.

**Das AAL-Magazin Mai/Juni 2010**

Das AAL-Magazin Mai/Juni 2010 beschäftigt sich mit den zukunftsorientierten Technologien, die für das Wohnumfeld von morgen relevant sind. Die Artikel erläutern, wie die Technologie dem Leben der Menschen eine bessere Qualität verschafft.

**Apotheken Umschau Januar 2010**

Apotheken Umschau Januar 2010 gibt einen Einblick in die neuesten Entwicklungen im Bereich der Apotheken, die eine bessere Versorgung der Patienten ermöglichen. Die Artikel zeigen, wie die Technologie die Apothekenwelt verändert.

**Focus April 2010**

Focus April 2010 gibt einen Überblick über die neuesten Entwicklungen in der Medizin und der Technologie. Die Artikel erläutern, wie die Technologie die Lebensqualität von Menschen verbessert.

**Smart Homes Mai/Juni 2010**

Smart Homes Mai/Juni 2010 beschäftigt sich mit den neuesten Entwicklungen im Bereich der Smart Homes, die eine bessere Lebensqualität von Menschen ermöglichen. Die Artikel zeigen, wie die Technologie die Lebensumgebung von Menschen verändert.