innovation
creativity
vision

annual report 2003

Institute of Microelektronic- and Mechatronic - Systems gGmbH

IMMS

You set the goals - we help to carry out them

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The IMMS – a capable partner for industrial research and development

In 2003 the Institut für Mikroelektronik- und Mechatronik-Systeme GmbH has continuously and successfully extended its research and development competences.
This, on the one hand, applies to the cooperation with semiconductor foundries, design centres and the developments in the area of sensor technique and electronic signal processing closely connected to it. It could be taken advantage from the infrastructure for testing and measurement of micro and optoelectronic structures recently developed in the institute branch Erfurt.
On the other hand, partnerships have been further developed or came into existence, which are dealing with the use of fine adjustment drives in different industrial application fields.
In all fields of activities of our institute the interdisciplinary aspect of the consultation of scientists with special knowledge in microelectronics, mechatronics, information technology/ informatics and semiconductor electronics has again proved to be very successful.
In this context the already existing departments

- system design
- microelectronic circuit engineering and
- mechatronics

have been supplemented by another one with the designation

- industrial electronics and measurement engineering

on the basis of the already existing cross-section area "analysis and test".

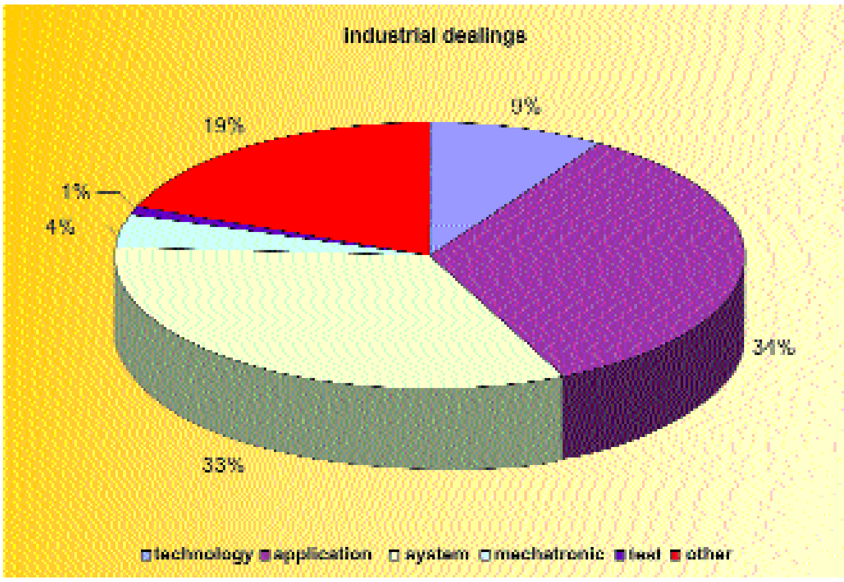


Fig. 1: representation of turnover per department

Owing to the increasing importance in characterization, qualification and validation of components, circuits and customer-specific integrated assemblies including the PC-based test method developments for mixed-signal applications, this has turned out to be necessary and useful.
With these measures we will be able, to prepare ourselves even more effficiently for the extension of complex customer-specific service performances and with that to be a reliable research and development partner for industrial companies in and outside the Free State of Thuringia.
Fig. 1 shows a proportional representation of the state of industrial sponsored research in our institute.
Also in future we will to an increasing extent direct our efforts to solid, long-term partnerships, with innovative companies of microelectronics and mechatronics trades. The aim is, to efficiently integrate the competences with such partners, existing and being developed in the institute, into research and development of products suitable for the world market.
Here, the cooperation of the IMMS with the design house "Melexis GmbH" and the Wafer-Fab "X-FAB Semiconductor Foundries AG" at the location Erfurt south-east is serving as an example. Besides the concrete support at the design of integrated mixed-signal circuits, eg. for automotive applications, MEDEA/BMBF-projects for design automation are successfully handled in basic research by means of new or improved methods. With that the improvement in design efficiency, regarding faultlessness, robustness and yield optimization at simultaneous reduction in the design periods for the integrated circuits to be realized in various technologies, is strived for. Also of advantage for this cooperation is a. o. the possible utilization of the new infrastructure (s. fig. 2) at the location Erfurt, in which the partners mentioned above can carry out their activities in direct neighbourhood.
Comparably successful are the efforts of our institute, to put the existing know-how in the area of measuring, drive and positioning systems into practice in a successful development of indus-

trial products together with our partners at home and abroad.
These innovative developments of drive systems are characterized by high accuracy and dynamics, which can be optimally adapted to the various applicative requirements.
Here new physical efficiency principles are used, which, for example, are continuously developed in projects of the DFG-financed fundamental research together with the Technical University Ilmenau.

ments carrying out their joint activities, in order to successfully cope with the increasing complexity of the system specifications to be realized.
Having this demand in mind, we will optimistically tackle the tasks to be dealt with in the year of 2004.

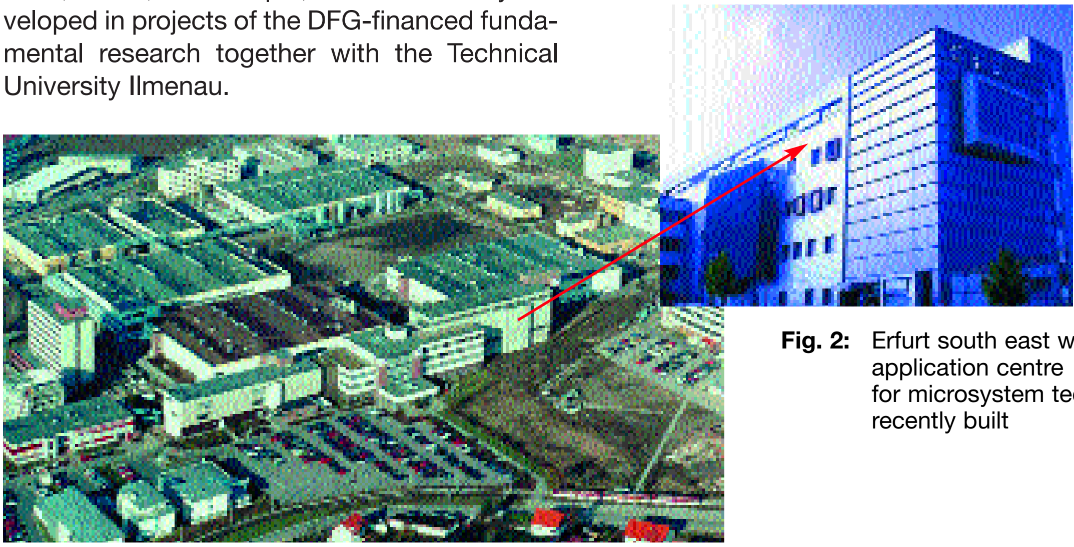


Fig. 2: Erfurt south east with the application centre for microsystem technology recently built

Also last year our status as an AN-institute at the TU Ilmenau again proved in many different ways. Numerous students have integrated themselves into research and development projects of the IMMS, starting with their activity as student workers in practical training, dissertations and final diplomas.
On the other hand, the scientific staff members of our institute carry out seminars, practical trainings and lectures at the faculties of the university so that for both sides an advantageous cooperation can be continued and constantly be build up.
The report on hand contains an overview of the scientific key competences of our institute in the four departments.
Our strong point is in the interlocking structure of disciplines, which is represented by highly qualified scientific staff members in the disciplines of the design of micro and optoelectronic as well as complex mechatronic systems. The competence and creativity of our scientific personnel allows the research and successful development of technical systems, which in all departments of our institute support the existing and constantly developed know-how. There are hardly any research and development projects, in which there are not staff members from at least two or three depart-

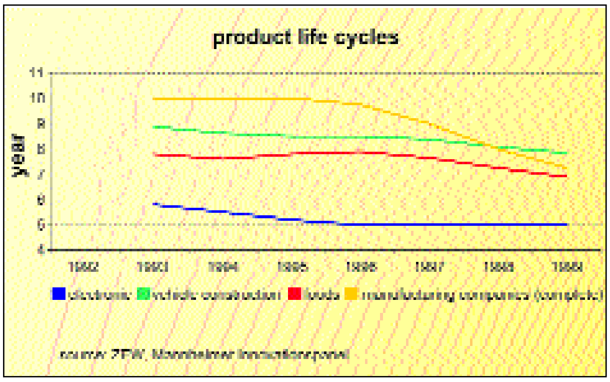
The management would like to thank all the staff members of our institute for the commitment they have shown and says “thank you” to all partners from industry, science and politics, also the staff members of the supervisory board and the scientific advisory council, for the successful cooperation.

Hans-Joachim Kelm
Commercial manager

Prof. Dr. Gerd Scarbata
Scientific manager

Cooperation as a door opener for innovation

Innovations are an expression of technical advance and an important precondition for the long-term existence of companies on the market.

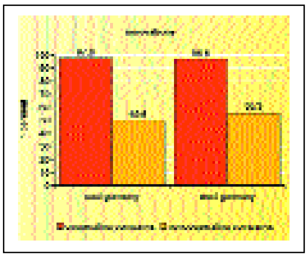


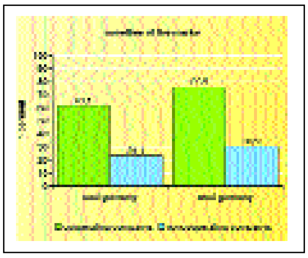
From several points of view innovation processes show a high complexity. They reach from the innovation idea over research and development to marketing. R&D is therefore part of innovation processes and cannot be looked at separately from the other elements of the innovation chain. Innovations are generally based on new scientific knowledge, by which new solution principles, procedures, methods and products are allowed. This often includes the requirement for new measuring and testing techniques. That way product and process development are not rarely closely connected with each other. To an increasing degree modern solutions are combined with information and communication techniques. The resulting diffiiculty and complexity, together with the technical system character and the novelty degree of the solutions, demand consultancy, qualification and application preparation at the user. This results in the requirement for a more precise devision of labour, with the aim of completely mastering future innovation processes. At the same time it is more and more required from R&D processes that they come up to the interdisciplinary character and system features of expected solutions.

For economical reasons individual companies have more and more concentrated on their key competences. Operational functions, being to much a cost burden, not sufficiently utilized or requiring too high investments, are dislocated. This all leads to an enormous economic pressure on the realization of R&D results. The importance of R&D for economical growth has become decisive. This is all the better accomplished, the more concrete market requirements build the starting point for a determination of the R&D tasks and goals.

Intensive customer and market contacts offer the possiblity for analysis and deviation of adequate requirements on R&D. Such contacts are, last but not least, made during the execution of service performances. They are necessary, in order to achieve a high effectiveness of the R&D results at the customer, to enable him, to master the systems developed and at the same time allow the reflux of experiences from application preparation and utilization of innovations. Services of this kind, which allow the integration of experiences from the realization in R&D, from the customer's point of view increase the quality of R&D results.

If more precise division of labour goes along with cooperations, the value of an innovation is no longer determined by one single innovator, but by a network of relationships between the innovating participants. Decisive for the success is trust, openness, definite goal agreements, regular communication on the way of procedure, agreement on interests and coordination as well as suitable contractual provisions. This allows synergies in the sense of a mutual spillover. The development of suitable cooperation networks requires time and more and more turns out to be an important factor in international competition. Cooperation and innovation are in a close reciprocal relationship.





The survey of the IWH on innovation cooperations of September 2003 proved that cooperative companies in general also make innovations and that most of the market novelties are produced by them, by which they generate important turnover shares. Most important cooperation partners of the companies in the young federal states are universities and research institutes. In contrast to that industrial clusters are of great importance in the old federal states. Scientific partners, last but not least, are closing the gaps that are still existing in the industrial structures of East Germany.

Innovation and marketing

The capability of an economic location will in future be decisively influenced by the fact, how it is managed to increase the chances for the small and medium size sector of the economy and to withstand the competitive pressure. This especially applies to the new Federal States and in particular also to the Free State of Thuringia, the economy of which is to a large extent characterized by small and medium enterprises (sme).
Innovations are the way to competitiveness, stability and growth. They are a process, in which knowledge becomes money. New knowledge, however, is gained from research. The landscape of science required for that has in the previous years continuously been built up. The IMMS has positioned itself very well among the R&D-facilities, close to economic reality, with future-oriented activities. From the beginning the main emphasis of research work was put on the purpose, to transfer their results into subsequent industrial application research and development. The main foci are put on: methods for design automation for complex microelectronic circuits, nano positioning systems, methods for analysis & test as well as the design of complex embedded systems.
Based on the intensive research and its results, market-oriented competence fields and R&D service segments are developed.
Small and medium enterprises have found a suitable partner in the IMMS, with whom they can quickly, reliably and lastingly close the gap between latest scientific knowledge and the development of innovative products from different areas (fig. 1)

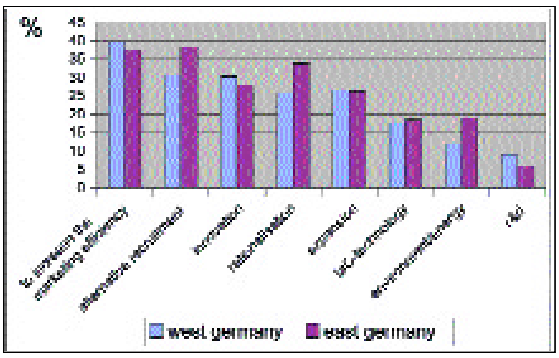


Fig. 1: regions of investment of sme (2003–2005)
Source: IfM Bonn 2003

The functionality of innovative products is to an increasing extent determined by complex mechatronic systems and solutions. This in particular applies to the most important trades of micro and precision engineering, automation technology as well as sensor, measuring and control techniques. The corresponding markets are characterized by high dynamics and high growth rates.
Here, the trade overlapping way of looking at the situation in the competence fields usefully shows to advantage. Combined with a lead in know-how, experiences from practice, an interdisciplinary way of thinking and working methods as well as by mastering the state-of-the-art techniques and design methods, we can optimistically take up these challenges.
In future the IMMS will not only stand for microelectronics and mechatronics, but will also offer its customers and partners innovative products and services, which, for example, are inevitable for tasks in the area of miniaturization, positioning and real-time measurement.
The interest at decisions for systems based on mechatronics is oriented to the surplus value, resulting from the application and its usefulness.
Market analysis and market investigation are the basic principle for an early recognition of technological trends, key technologies and technological future visions.
This is supported by the direct vicinity to the TU Ilmenau. The results from that decisively determine the goals followed by the institute.
Besides the concentration on market-oriented competence fields the further active involvement in regional and trade-overlapping clusters is absolutely necessary.
Owing to the aspects mentioned, the marketing of advanced technolgies itself becomes a challenge. To be able to do something, to know something, to invent something is considered to be a challenge; to organize the process accordingly, to support networking, to find and involve partners, requires a model, which in our scientific landscape is not yet widely spread. To extensively develop these preconditions for success as "capability", will to an increasing extent determine the activities of the IMMS.

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Objective

In the Mechatronics Department, precision drive systems are designed, analysed and tested for the most varied fields of application. The work involves not only design and construction but also optimisation. The latter is achieved by modelling and simulation of the heterogeneous systems, which in some cases are extremely complex. The modelling permits accurate and dependable predictions of the systems' behaviour, for example with respect to mechanical deformation, dynamics, and magnetic or thermal behaviour, so that the number of design cycles is reduced to a minimum. The tools used for the purpose include Ansys, Maxwell and Matlab/Simulink. Design and construction is supported by Mechanical-Desktop, Inventor or Pro/Engineer.
The subjects addressed by the Mechatronics Department:

- direct drive systems
- analytical tools and equipment
- drives for use in UHV and
- complex mechatronic systems

are subjects which overlap even within the Department of Mechatronics on the one hand, and, on the other, are closely linked to the fields of System Design and Industrial Electronics and Measurement Engineering.
Our approach in project work is, above all, to take a holistic view of the system and its optimisation. Close interdisciplinary co-operation between experts combined into project teams and staff from the commissioning company is always the pattern.

Special fields of application

To take some examples, drives that have been designed at IMMS have the following characteristics:

- high accuracy and excellent dynamics even in multi-track movement (in the case of multiaxial direct drives)
- the use and combination of a variety of physical movement principles (e.g. electrodynamic, electromagnetic or piezo-electric).
- control by means of systems with innovative strategies.

We find tailor-made drive solutions or applications and adapt them with suitable sensors and control systems for integration into plants and equipment. We also command considerable knowledge on which to base the design of plants by combining conventional drive, sensor and control components.
Measurement and control systems are available in plenty to help us assess and optimise the drive properties and to carry out rapid prototyping when designing the best regulatory software. We have developed or are still in the process of developing and investigating:

- Design and modelling of drive systems for Microsystems technology, p. 9
- Development of an online measuring system for rheological properties of liquids, p. 10
- BASALT – AT Adhesion Tester, p. 11
- Linear Motion System LMS 20, p. 13
- Design of mechatronic precision drive systems, p.15
- Comparison of controller concepts for path control of planar hybrid step motors, p. 17
- Multiaxial positioning systems, p. 19
- Layout and optimization of passive magnetic bearings with modern design methods, p. 21
- Development of a modular micro-tribometer and a probe-magazine for using in the field of UHV, p. 23
- Planar electrodynamic direct drive systems
- Devices and instruments for analytical purposes (e.g. microtribometers)
- Design of digital regulating systems with multiple axes.

Tasks we envisage for the future are:

- drives for wafer positioning systems
- optical surface measurement technology
- positioning systems for the nanometer range and wide fields of movement.

In 2003, four patents from the Mechatronics Department were granted. (p. 24)

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Design and modeling of drive systems for micro technology (MODAN)

BMBF, 169V1554

Objective

As part of the R&D-project funded by the BMBF (Federal German Education Ministry), IMMS is involved on two fronts. The first is the evaluation of simulation tools intended to support engineering design in the sphere of mechatronic drive systems. Specifications are to be derived from these investigations which will assist in further developments of design methodology, with particular relevance to the simulation software "SimulationX" and "SESAM".

The second field in which IMMS is engaged for the project is the development of a variety of mechatronic drives:

- precision drives with a modular design, for instance electro-dynamic direct drives and those based on magnetic reluctance
- mini and micro drives, again modular, such as actuators relying on electro-magnetic resonance or those on piezoelectric principles.

Furthermore investigations are carried out concerning the use of precision drive systems as described above in multi-axis machines under real operating conditions.

The development process of the precision drive systems will be described in a way so that it can be reproduced in the simulation software to assist the next developments of such stages step by step. Likewise the outcomes from simulation are constantly compared with the results of development and testing of the drives under real operating conditions.

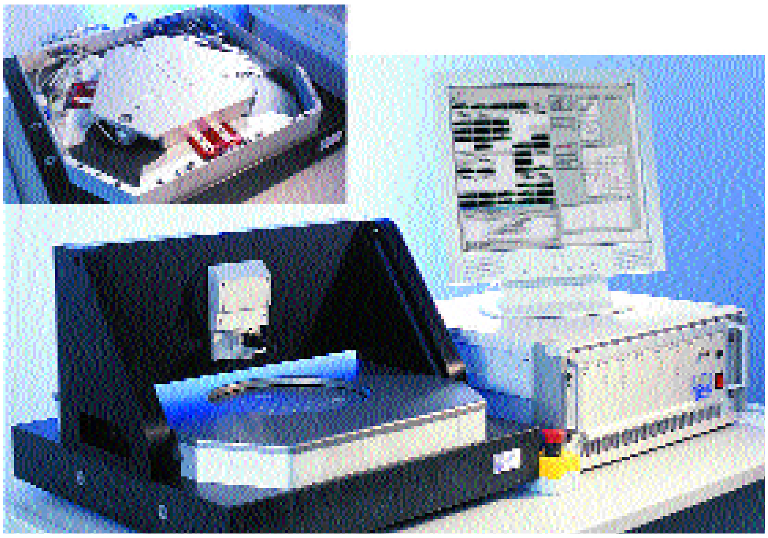

Fig. 1: electro-dynamic planar motion system PMS100-3 for use in analysis equipment

Progress and status of research

Working groups have been established from the very first so that the simulation tools can be evaluated in relation to particular drives. In parallel, requirements were established for the designing and creation of the drives.

Many preliminary investigations were carried out with several experimental setups. They have influenced, for example, the development of the electro-dynamic planar direct drive PMS100-3 shown in Figure 1, and the electro-dynamic linear direct drive LMS20 shown in Figure 2. Currently, the "SimulationX" tool is being evaluated in relation to actuators relying on piezoelectric principles and electro-magnetic bearings. The "SESAM" tool is being evaluated on electromagnetic resonance actuators and on electro-dynamic direct drives. Additional simulations have been realized with Maxwell/Simulink and ANSYS.

Outlook

The future will see a continuation of this work on the drive systems and in parallel the further evaluation and development of the software.

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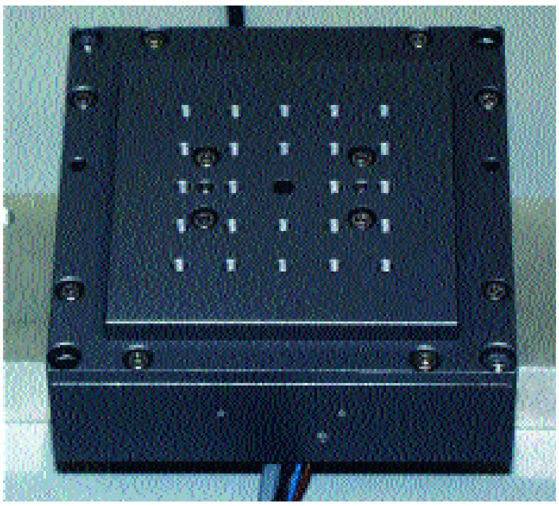

Fig. 2: electro-dynamic linear motion system LMS20

Development of a measuring gauge to investigate the flow properties of liquids (RheoFilm)

EU, G6ST-CT-2002-50165

Objective

IMMS is participating in a European R&D-project together with two German companies, and one company an a research centre each from Belgium, Spain and Switzerland. For IMMS the work involves developing and testing a measuring system for micro-rheological features of films – a rheometer. The subjects of the measurement are thin or viscous films of organic or inorganic composition. Not only is the measuring procedure being developed, but also a calibration method for the rheometer and fluids which can be used for calibration. Therefore a device concept had to be developed including measurement and control algorithms and software. More is required: all the measuring equipment, data recording and analysis programs must be capable of online connection and functioning so that their performance can be demonstrated in an online group testing session, a "ring test" (round-robin test).

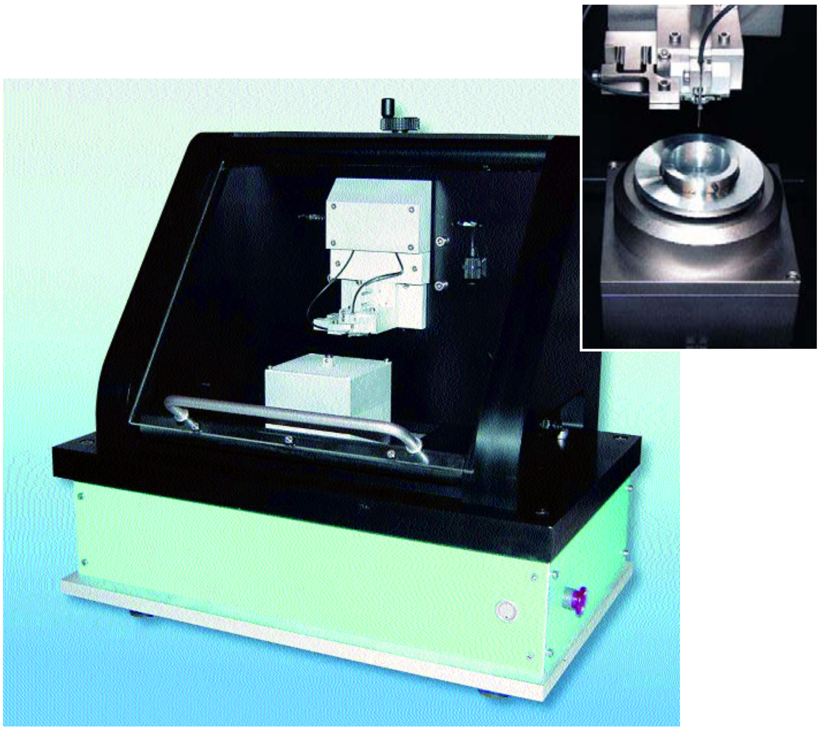

Fig. 1: Rheometer prototype

Progress and status of research

The starting point was the definition of the demands the rheometer must meet. The differing requirements of the project partners were taken into account: on the one hand, the conditions for a laboratory set-up, on the other hand, the fields of application and their needs. The detailed project definition was a reflection of up-to-date research outcomes in the basic research (R&D-partners) and/or the specifications of the customers, defined by the industrial partners. That regards for example, the lubricants (their viscosity, composition, etc.) to be investigated by the rheometer, the design of the samples and counterbodies (material, surface characteristics etc.), and the experimental conditions (temperature, humidity, air pressure, mixture of ambient gas, length of test, etc.). The review of all these requirements led to a device specification that was then the basis of the development of the rheometer.
A prototype (see Fig. 1) has been developed and verified with the characteristics described in the specifications. The prototype can be used online via telephone line or Internet. The round-robin test with all partners will be realized in the beginning of 2004. Every partner group in Spain, Belgium, Switzerland and Germany owns one rheometer. They will be used during this round-robin test with similar experiments on all four testers. Controlling of all four devices, data analysis and visualization of the results will be realized from one place, namely IMMS.

Outlook

Continuing work within the project will be the testing of all rheometers by the project partners depending on their own experiments. The results of these investigations will be the basis for further development.

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Adhesion Tester BASALT – AT

Objective

In the context of a R&D co-operation between IMMS and TETRA GmbH, it is intended to develop a system for analysing and machining objects in the field of precision engineering in the range of micro- and nanometers. As an all-purpose system, the fields of application will range from testing material characteristics and material coupling resp., especially regarding adhesion, indentation, and scratching, to tribology, to tension/torsion testing and even to micromanipulation.
In order to meet such numerous demands and to enable the user to choose only the functions he really needs, the BASALT–AT shows a modular design. This allows very simple configurations as well as setups with a wide range of functions and components. It is also intended to upgrade an already existing adhesion tester.

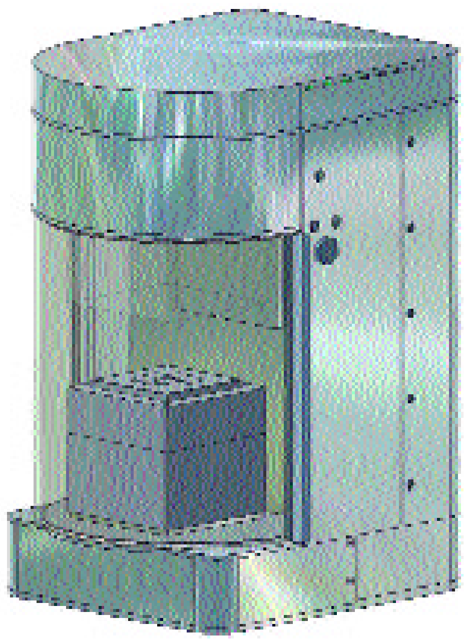

Fig. 1: adhesion tester BASALT-AT

It is possible to run the system in a network. On the one hand, this allows the operation of several systems in parallel, and on the other hand, it can be implemented in existing networks. In the same way, single modules can be coupled by high precision planar or linear drives.

Design

The Adhesion Tester is composed of the following components:

■ ***base frame***

The base frame is a very stiff low-vibration body with the dimensions 200mm x 350mm x 255mm and an integrated z-drive. Apart from the central control unit, it includes all supply and control units both to communicate with external systems and to operate the single modules.
The z-drive applies a pre-stressed ultra-precision guide which provides a 50mm lift. It is precisely driven by a stepping motor in microstep mode, which allows vertical movement in steps of 125nm.
The detection of the z-position is initially realised by counting the motor steps. To increase the system accuracy and to gain absolute values, the z-drive can be upgraded with a measuring system with 50nm resolution. This measurement signal can also be used to control the piezoelectric actuator that is already included in the z-drive to excite vertical oscillations and for possible further applications.

■ ***foot***

The foot forms a constructional unit together with the base frame that gives stability and footing to the overall system. The foot contains a planar positioning system to place the probe in the x- and y-direction within the travel range of 20mm. The positioning system can be manually activated via adjusting knobs or driven by small stepping motors.
The probes can be attached to the top plate using a grid of threaded holes, while the top plate is specially designed to allow the assembly of other modules. For example the linear motor LMS-20 (p. 13) can be attached at this point. In this configuration the achieved performance parameters of the linear motor can be utilised for the Adhesion Tester.
It is possible to install further modules, while every single module features its own control unit and logs on to a central control unit via a special interface. Thereby every module receives its own network address.

■ ***instrumentation***

The instruments for length and force measurement are placed within the space of 90mm x 110mm x 90mm. They are designed as interchangeable modules and use a standardised interface. They also log on to the central control unit with their own addresses. There is a special retainer for TETRA-Cantilever, so that it

is possible to use already existing components and technologies. The instrumentation allows a biaxial force measurement within a range from 10nN to 10N.
These modules are attached to the z-axis. Therefore they can utilise both the z-drive for coarse positioning and the piezoelectric actuator for fine positioning. There is also the possibility to apply an extra drive within the modules for measurement movements.
Modules for micromanipulation and micromachining complete this line-up.

- ***probe chamber***

The space where the probes and the instruments are placed can be sealed by a transparent shutter. If necessary, the chamber can be supplied with a special atmosphere, using the provided supply connections.

Status of research

The Adhesion Tester was developed by IMMS GmbH in close cooperation with TETRA Gesellschaft für Sensorik, Robotik & Automation mbH in best time.
The fully developed design in conjunction with the modular software and sophisticated electronics make the BASALT-AT a high tech device. The application of high-precision components along with the modular mechanical design provide a durable and multifunctional solution for any laboratory equipment.

Outlook

Due to the modular design, the BASALT-AT can be assembled in numerous configurations. For very simple applications it is also possible to set up the foot without a system for horizontal probe positioning. In this case a simple plate with the clamped probe allows manual positioning of the probe, while the operating range is also 20mm in both directions.
Another option is a foot with a feedthrough, so that the Adhesion Tester can be attached on top of larger containers.
The optional instrumentation with a camera makes it possible to watch the contact area during measurement, which is essential, especially for micromanipulation.

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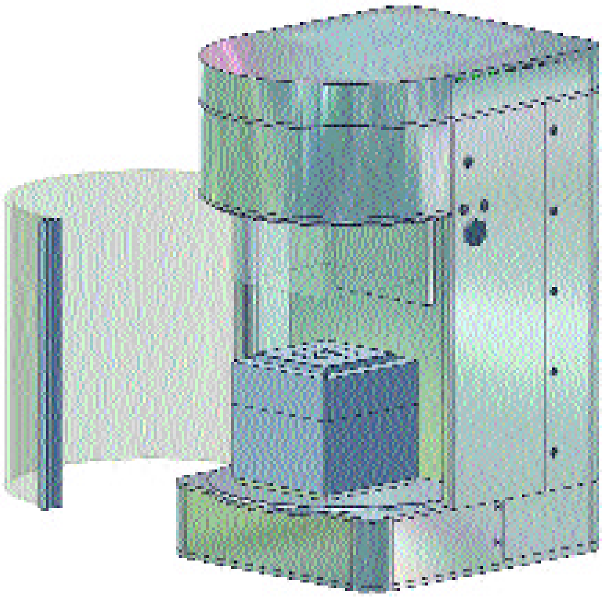

Fig. 2: probe chamber open

Linear Motion System LMS 20

Objective

Quickly reaching a position and precisely keeping it with a reproducibility of 1µm and a holding force of up to 2N are great but nowadays absolutely common requirements for a mechanical system. Furthermore, a steady movement is wanted.
The goal is the development of a line of linear motors with small dimensions that meet the above mentioned demands for varying travel ranges. This research is part of a R&D co-operation between IMMS and TETRA GmbH.

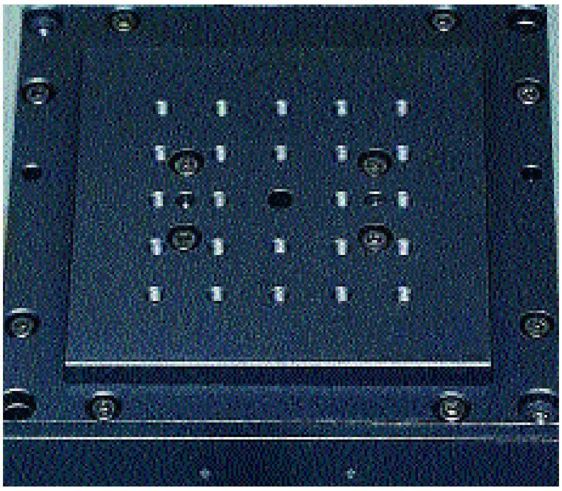

Fig. 1: LMS 20 first prototype

Progress and status of research

IMMS is designing electrodynamic precision drives including appropriate control hard- and software.
On this basis, a linear motor was designed that can be applied in various scientific devices, preferably for probe positioning. Based on two ultra-precision linear guides, the linear drive could be realised within the external dimensions of 90mm x 90mm x 35mm. As a result of extensive enquiries and preliminary tests it was possible to find a linear ball track that runs smoothly and without shock and that shows a synchronous run of better than 1µm. The system is propelled by an electrodynamic drive.
Since the propulsion coils are placed on the stator and the permanent magnets are carried by the moving part, there is no trailing cable disturbing the precise motion.
Photoelectric sensors in combination with an incremental scale form a measuring system with a resolution of 50nm. The measuring system provides relative values as well as absolute values with regard to a reference marker.
Limit switches and mechanical stoppers complete the system.
The linear motor is applicable in clean room conditions and has an overall mass of 580g.

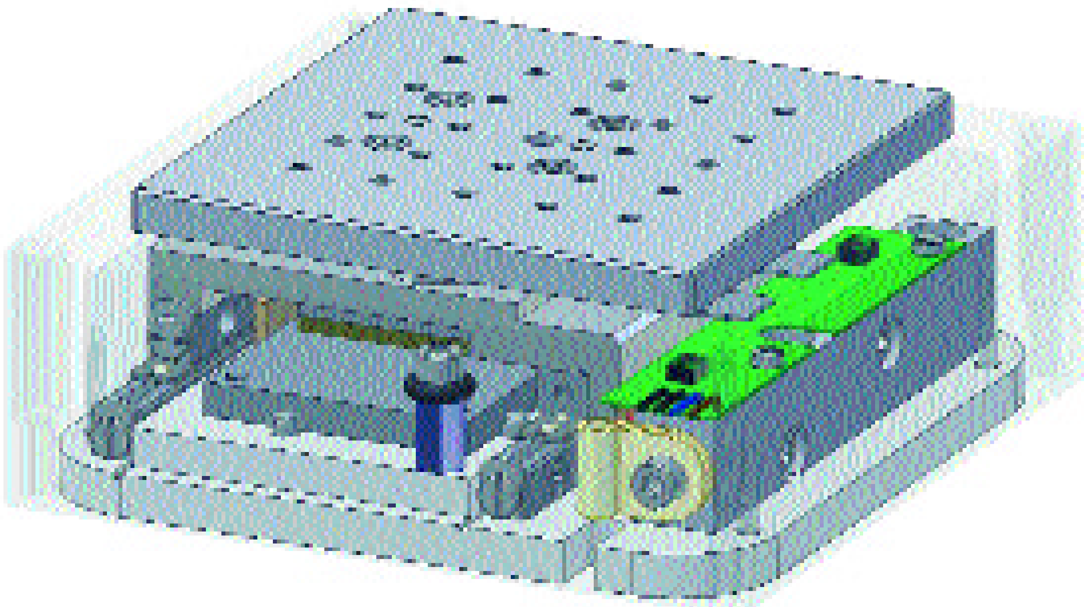

Fig. 2: interior view

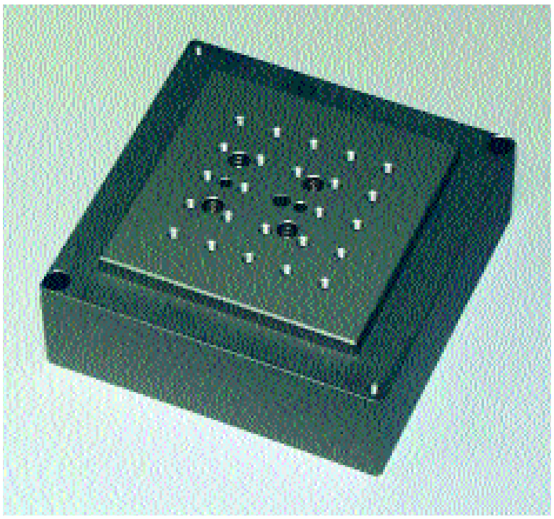

Fig. 3: linear motor LMS 20

Results

The LMS 20 covers a travel range of 20mm. With a positioning velocity of 30mm/s and an acceleration of up to 5m/s² the claimed reproducibility for reaching and keeping the target position is achieved, while the full accuracy potential is not yet tapped. With these parameters the drive operates up to a maximum drive force of 2N, while the maximum normal force is 10N.
Apart from the favourable horizontal operating position, any other position (e.g. vertical position) is possible with certain limitations.
With respect to the claimed accuracy, the LMS 20 is run like a commuted servo motor. The control unit reads the present position via a digital encoder and then calculates the commuted currents for the propulsion coils. The power amplifiers are then controlled by a pwm-output.

Outlook

The further development will turn the LMS 20 into a stand-alone system. In order to do so, the control, including a 16-bit microcontroller, will be integrated into the case by placing it directly underneath the motor.
The final goal is to design a complete system with integrated controls.
The introduced linear motor is the basic model for a line of other linear motors with modified parameters. The next step will be the development of a similar drive for a travel range of 50mm.

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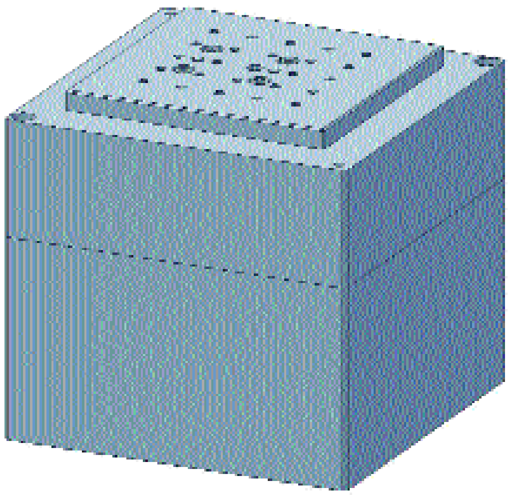

Fig. 4: complete system with controls

Design of mechatronic precision drives

DFG, SFB 622

Objective

In the collaborative research centre 622 „Nanopositioning- and Nanomeasuring Machines“ promoted by the Deutsche Forschungsgemeinschaft, the scientific-technical foundations for the design and the realisation of nanopositioning and nanomeasuring machines are developed. These machines enable positioning, measurement, touching and processing of objects with nanometer accuracy and therefore occupy a central position in future-orientated technologies and techniques such as the semiconductor technique, biological and genetic engineering, but also electronic beam and x-ray lithography. Numerous technological fields of application determine the major challenges for the collaborative research centre: Covering large travel ranges of several hundreds of mm with nanometer accuracy and high positioning velocities.
In the context of this collaborative research centre, IMMS concentrates on the development of nanopositioning systems providing large travel ranges. For a nanopositioning and nanomeasuring machine with an operating range of 200mm x 200mm x 25mm an appropriate motion system has to be developed. Apart from the selection and the design of suitable drives, the research also comprises the examination of different concepts to arrange drives and guides in order to meet the high precision demands. With the objective of an aerostatic guidance several types of air bearings have to be tested with regard to their applicability in nanopositioning systems and a suitable guidance concept has to be developed.

Progress and status of research

In line with the investigation of aerostatic bearings, an interferometric measuring setup was realised to detect the remaining noise of planar air bearings perpendicular to the guide way. The results showed that common nozzle bearings cannot be applied in nanopositioning systems, due to a remaining noise with amplitudes of ± 5nm and frequencies of 5 – 100Hz. With porous media air bearings, an amplitude reduction down to ± 1nm could be shown.

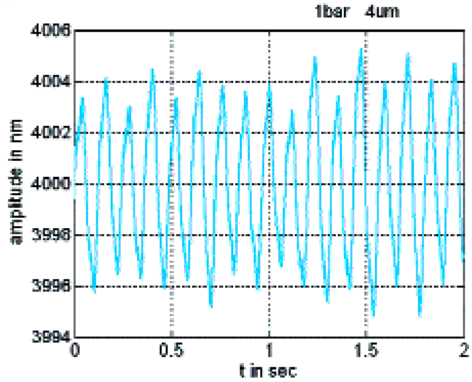

Fig. 1: remaining noise of a planar nozzle bearing

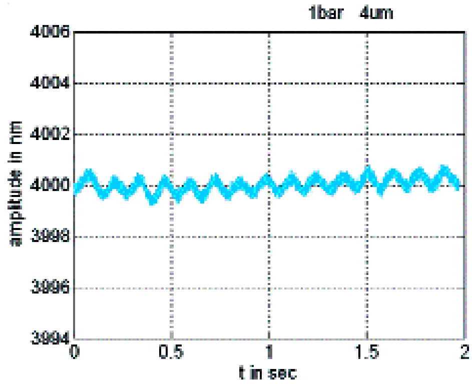

Fig. 2: remaining noise of a planar porous media air bearing

In the course of the development of a motion system for the nanopositioning and nanomeasuring machine, different design and arrangement options were evaluated and compared. To do so, principles for the drive propulsion system and the guidance system were developed and compared applying both planar and linear air bearings.
In order to examine the applicability of the cylindrical linear air bearings (air bushings) in the field of nanopositioning and in order to provide interchangeability with ball bearings for vacuum applications, the development process focussed on this guidance option. The finally favoured principle was then implemented to build up a 3D model of the motion system.
As a result of the principle evaluation, a solution with a serial arrangement of linear air guides with two cylindrical guiding units for each axis was selected. The applied bushings contain a cylindrically shaped porous media layer where the compressed air radially enters the circumferential air gap. Moreover it is intended to use a symmetric arrangement of two electrodynamic direct drives for each moving direction, so that four direct drive units synchronously act

on the moving part to position it in the x- and y-direction. This concept leads to a favourable dynamic behaviour. Moreover, the peripheral position of the drives reduces their disturbing thermal influence on the measuring area and also allows a convenient and well directed heat removal by a cooling system.

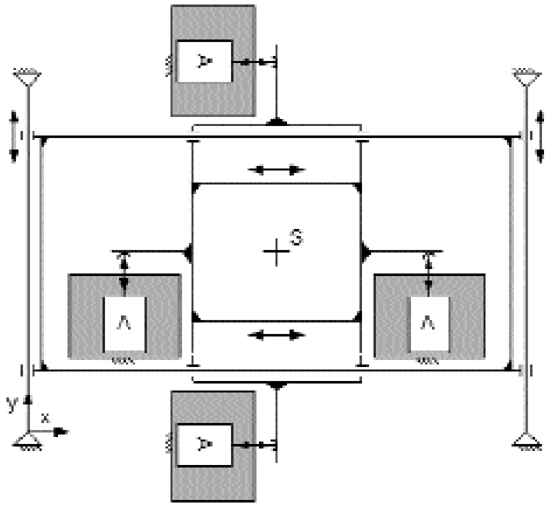

Fig. 3: favoured option with linear guides

Based on this principle a 3D model was created, while the components of the drives and guides were implemented and vital details for nanopositioning were considered.

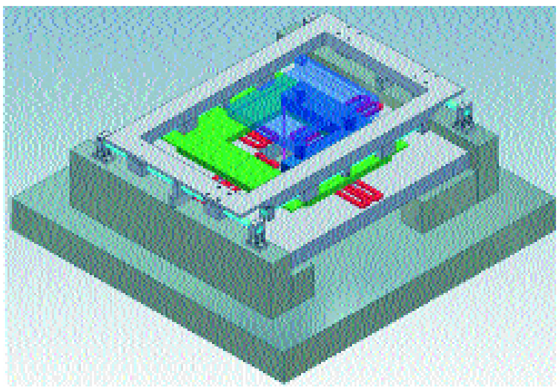

Fig. 4: 3D model with linear guides

Outlook

To investigate the characteristics of the cylindrical air bushings especially regarding the static and dynamic stiffness and the remainig noise, the next step will be to build up an adequate measuring setup. The results and conclusions of these measurements will then be implemented to improve the 3D model. Furthermore, the developed concept will be gradually enhanced, leading to the realisation of a prototype. The experimental examination of this prototype will then provide the basis for comparison between the developed concept and other concepts and for finally selecting one to be implemented in the nanopositioning and nanomeasuring machine.

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Comparison of controller concepts for path control of planar hybrid step motors

TMWFK, B609-01040

Objective

In mechanical engineering all over the world it is intended to achieve higher speeds and higher levels of accuracy. In the field of drives and actuation this leads to a trend towards the use of direct drives, as these drives avoid the disadvantages of common rotary spindle drives, such as clearance and resilience. The fact that there is no gear unit with direct drives reduces size and weight and improves dynamics. In order to tap the full potential of direct drives regarding precision and speed, it is not enough simply to operate linear step motors in an open-loop control system. In fact closed-loop control of these drives is necessary.
As part of a joint project funded by the TMWFK, the Thuringian Ministry of Science, Research and Art, new-type, non-linear algorithms are developed to control step motor drives. The goal is to exploit the advantages of planar direct drives and at the same time to achieve long traverse paths, high speed ratios, and a favourable engine smoothness, regardless of the velocity. To meet these demands, particular models of the dynamics involved are necessary, together with ideas and algorithms for suitable and effective control systems. In this context, the main topic for IMMS is the development of multiple-axis feedback and control systems for path control.
In the course of research, two methods have turned out to be most suitable for the control of the drives. They are compared below.

Progress and status of research

A planar step motor is used in order to realise and prove the controller concepts. The motor has three degrees of freedom: the translation in vertical and horizontal (x- and y-) direction as well as the rotation in the moving plane.

The used motor has three power generating units (one acting in the x-direction and two acting in the y-direction).
The rotation of the motor has to be understood as a disturbance because as a consequence, the reachable force will decrease. Since the goal is to preclude the rotation of the motor, it is helpful to apply a separate rotation-controller (φ-controller) with setpoint zero. Under the aspect of path control the remaining degrees of freedom can be described as movement along the target path towards the destination.
The control is realised by a z-e-controller (complete controller, further denoted as z-e-φ-controller), whereas the lateral error in the trajectory is controlled to zero by the e-controller, and the distance to the destination point is controlled by the z-controller.
The second possible way is to utilise single axis controllers that can be applied to every partial motor. In this case, a x-y_1-y_2-controller is obtained.
Such a controller can easily be implemented via commercial hardware of various providers. For instance, there are solutions with up to eight axes with freely programmable encoders.

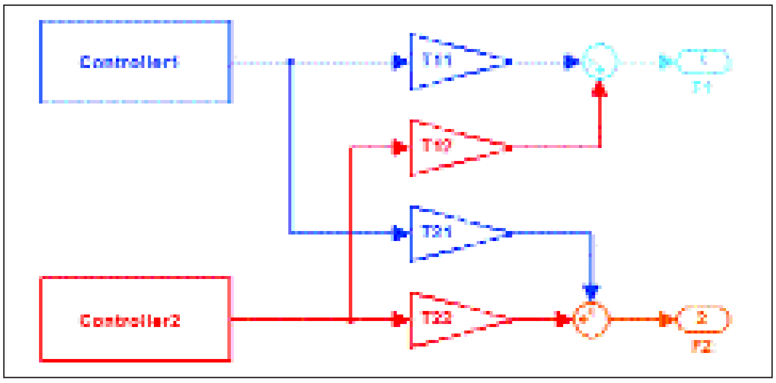

Fig. 1: method of decoupling of axes

The demanded setpoints can be distributed to the separate single axis controllers. The constraint of zero-rotation is fulfilled by the equality of the setpoints for y_1 and y_2. The control along a trajectory is more complex, since the setpoint has to be updated permanently.
The generated force of either y-axis retroacts to the other axis via a torsional dependency. The appropriate relations have to be considered in the controller draft (see fig. 1) by decoupling the axes. Such a cross linking is not possible with the hardware solutions available on market. Therefore decoupling is set aside, so that both y-controllers counteract in this case.

Presently, the influence of decoupling on the stiffness of rotation is analysed by means of Simulink models.

In contrast to the x-y_1-y_2-controller, the rotary controller of z-e-φ-controller can be tuned directly, which is advantageous for rotation steadiness. A decoupling of the y-axes is not necessary with the concept of this (z-e-φ-) controller. Also the z- and e-controllers are specially constructed so that the control deviation will be adjusted to zero. To apply this method, it is mandatory to transform x-y-coordinates into z-e-coordinates. Since that compute-intesive process has to be carried out in real time, the controller's hardware specifications are quite hard, so that in most cases expensive DSP-cards will be applied.

The assets and drawbacks of both controller types are shown in short form in table 1 on the next page.

	x-y_1-y_2-controller	z-e-φ-controller
+	■ direct transfer of one-dimensional controller structures ■ use of pre-implemented hardware possible ■ specification of path without compute-intensive transformation of coordinates	■ easy handling of rotation control (spec. tuning of controller) ■ automatic decoupling of axes
–	■ decoupling of y-axes mandatory (not possible with commercial hardware) ■ low stiffness of rotation	■ high computational effort for transformation of coordinates ■ use of pre-implemented controller hard ware not possible

Tab. 1: assets and drawbacks of discussed controller concepts

Outlook

The main focus of future work will be the development of a procedure for decoupling the axes for the x-y_1-y_2-controller which can be used with ready-made hardware. Furthermore, a path generator will be designed, allowing the user to drive complex geometric shapes.

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Multiaxial Positioning Systems

BMBF, 0312904A

Objective

The objective of the research project InnoSKo within the Inno-regio Südthüringen program is to design a machine tool, in order to cope with the high standards for modern laser precision processing.
The processing of complex component geometry requires the mastery of complex machine tools, i.e. enhancing 2D- to 3D-systems, and therefore a higher number of drive axes.
The first intermediate step should join an existing planar positioning system to a rotary and a spindle drive in order to get a compact multiaxial positioning system which satisfies the practical demands of users.
The existing DSP control system of the planar positioning drive should be reused for the complete system by taping the full potential of the hardware.

Progress and status of research

To realize complete component processing, diverse auxilary movement has to be provided in addition to the pure cutting geometry.
The additional drive axis will be controlled by a superior realtime application that will realize a widely autonomous process. Due to the repeat accuracy of the machine tool, there will be a consistent quality with high quantity.
The complete positioning system consists of

- amplifier box and industrial pc with DSP-realtime system
- planar drive with rotary axis and position measurement systems
- laser unit on z-spindle drive

The hardware has been dimensioned and physically realized.
The starting point for carrying out the project the innovation of which is to be found in software design, is the well-known Designflow with the following main aspects:

1. data-analysis, modeling and control design with high-level software tool MATLAB
2. modeling and graphical structuring of control hierarchy with SIMULINK
3. automated, specific code generation for controller application with REALTIME WORKSHOP

As a consequence of increasing complexity of machine tools and therefore increasing calculation and memory efforts, the design requires special attention to be paid to the hardware restrictions to get effective code from the code generator. In the sense of RAPID-PROTOTYPING designflow, there are some iterations to get a running and functioning DSP-application. Here, the automated designflow steps mean great advantages to the control engineer.
The following system hierarchy:

1. ***measurement system***
   - planar grid measurement system
   - incremental position measurement system
   - incremental position signals from resolver signals
2. ***controller***
   - planar controller (observer-based incremental riccati-controller)
   - single axis controller (observer-based incremental riccati-controller)
   - single axis controller (PID-concept)
3. ***output***
   - commutation and reordering of controller currents to the drive coils
   - error managment and start/stop procedures

helps with orientation while solving the problem step by step in order to get a structured solution to the complex overall problem.
Currently, final calibrations and tests are in process which seem to be successful.
The new machine tool will be tested in industrial use by LLT GmbH.

Outlook

Currently, possibilities for extension of the characteristics of the machine tool are already being considered. There will be next releases that will for instance provide a handwheel etc.
Experiences of the users have shown that it is effective if the machine tool can be used in different configurations during one production proccess. This will minimize machine downtime and increase user-friendliness. These are development topics of the future work.
In parallel, there are works on extentions to the controller strategy. A diploma thesis that will analyse and find some methods to synchronize single axes or to syncronize single axes to axis systems will be started in March 2004.

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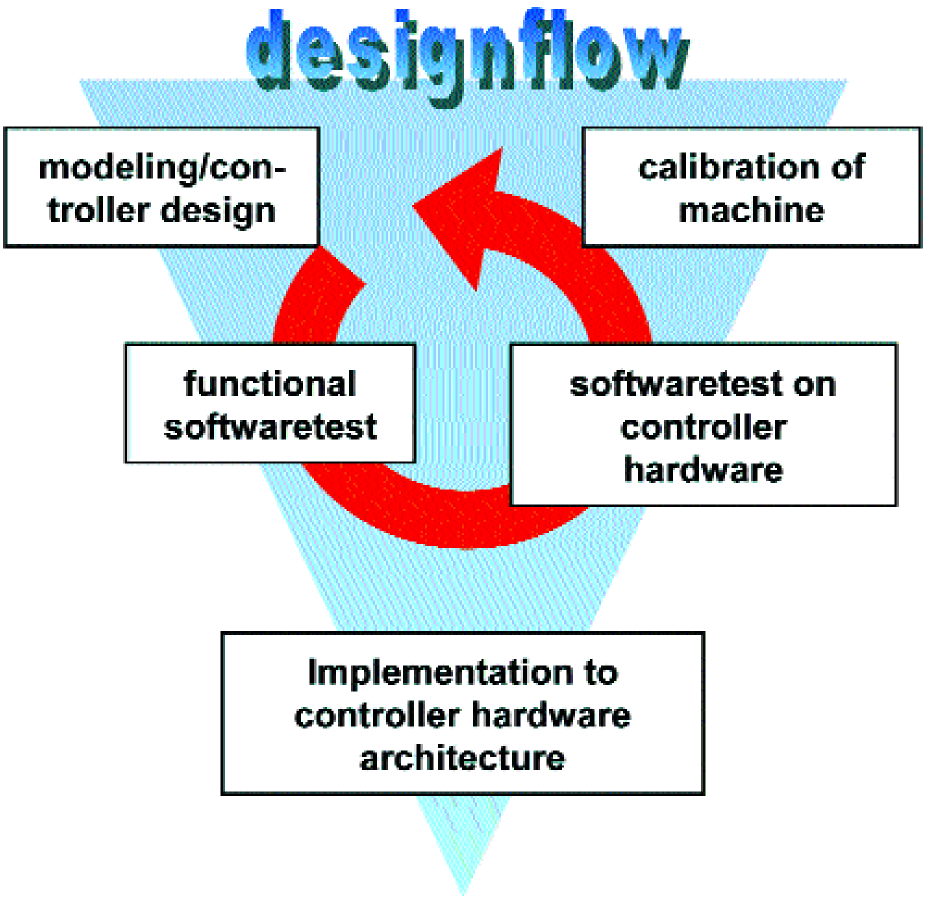

Layout and optimization of passive magnetic bearings with modern design methods

Objective

The fact that they are maintenance- and friction-free are the well known system advantages of magnetic bearings. Therefore magnetic bearings can be found in a lot of applications, especially for the suspension of high-speed rotating rotors. The commercial succes of an industrial application is therefore essentially determined by the optimal conversion of the bearing principle to the proper bearing during the design process.
A larger distribution of usually active magnetic bearings is restricted by higher acquisition costs in comparison with conventional bearings. A passive locking of degrees of freedom (DOF) could reduce these costs. On the other hand, the use of passive bearings results in greater development efforts. This is due to e.g. the missing damping and the multitude of embodiments.
The efficient development and design process of a passive levitated shaft is the topic of this project started in 2003. In this process, the project activities could incorporate results of a project finished in 2001 where a prototype of an active levitated shaft was designed, constructed and validated.

or more specific passive/active supported shaft requires the design and the optimization of one active bearing for the axial DOF and two passive bearings for the radial and angular DOF. Passive bearings do not include a damping. Therefore the design of inner (electromagnetic) or outer (mechanical) damping elements is necessary as a supplement.
The following key aspects of activity result from the specified tasks:

- magnetic modeling, simulation and optimization of the bearing components,
- characterization of the mechanical behavior of the shaft. This includes
  - the determination of the necessary bearing stiffnesses for given disturbances and
  - the optimization of bearing parameters like the bearing position
  - modeling and design of damping components.

Passive magnetic bearings use the Lorentz-forces as bearing forces which interact between magnets. The realization of the bearing principle can occur in different ways. On the one hand, repulsive bearings are based on repulsive forces between the magnets. On the other hand, bearings with attractive magnets are consequently called attractive bearings.

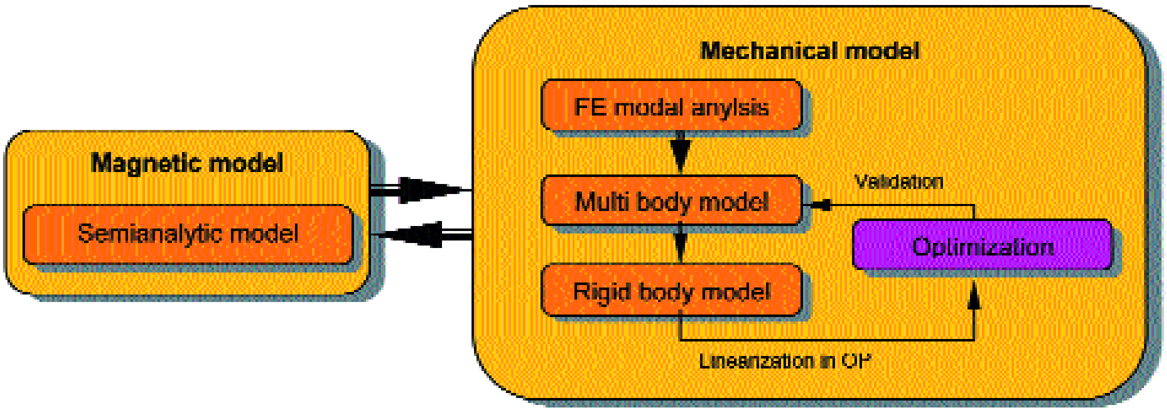

Fig. 1: model structure

Progress and status of research

Passive magnetic bearings cannot lock all DOF of the shaft relating to the theorem of Earnshow (special magnetic materials like diamagnetic materials or superconductors will not be considered). So one DOF has to be locked actively by a controller. In the normal case, the axial one is locked actively with regard to reducing the necessary active bearing components and consequently the costs. A passive supported

Furthermore, attractive bearings could be classified by the number of nested magnet rings in single and multiple ring bearings.
There is no principal bearing configuration which is ideally predestined for all applications, e. g. considering the parameter force per bearing volume. The use of multiple ring bearings increases the force per volume. Otherwise the acquisition costs of multiple ring bearings are higher in comparison with single ring bearings.

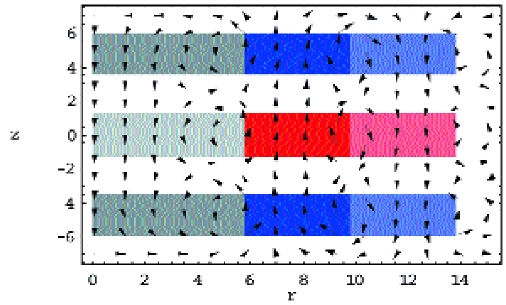

Fig. 2: magnetic field calculation of an attractive double-ring bearing (rotor-red, stator-blue)

a further reduction of model DOF. A rigid-body model will be applicable by which a linearization is taken at the working point. The proper optimization of the system matrices regarding a stable shaft behaviour is executed by *Matlab*. After the optimization, a time domain simulation follows in order to rule out linearization errors.

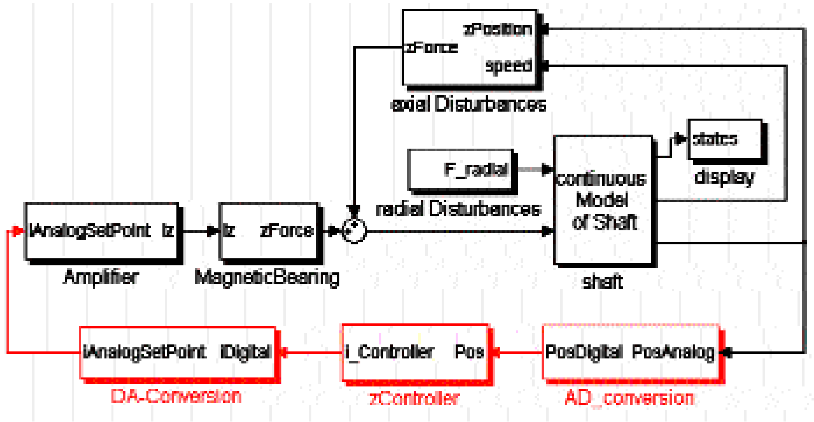

Fig. 3: Simulink-model for the time response simulation of the shaft

Hence the optimal bearing configuration is selected using an evaluation matrix. All relevant decision criteria like manufacturing, costs and mechanical stability extend into the evaluation matrix.
The purpose of the magnetic modeling is the design of magnetic bearings for postulated stiffnesses and the optimization of these bearings. The goal of optimization is the minimization of the bearing volume of the particular configuration (repulsive/attractive, single or multiple ring bearings) with respect to a given stiffness. Such an optimization requires a multitude of calculations. The chosen model approach is therefore a semianalytic one instead of a FE-model in order to minimize the calculation time. The basis of the semianalytic approach is the modeling of permanent magnets by cylindrical surface current. This leads to elliptic integrals which permit an efficient calculation of magnetic field terms like flux density, force und stiffness.
A 3D simulation resp. a bearing design by this software module takes only a few seconds. The reduction of calculation time – in comparison to FE-models – to a fraction allows fast computation of optimization calculations. As opposed to more simplified model approaches, the implemented model furthermore offers the possibility for examining the influence of material tolerances on bearing characteristics.
For the modeling of the mechanical shaft behaviour, a multilevel model approach was chosen. The starting point of the model are the results of a FE-model analysis. A multi-body model will be derived from these results.
The implementation of the multi-body model in a *Simulink*-model occurs in view of investigations in time domain – the effect of disturbances to the shaft behaviour could be simulated. The optimization of the bearing parameter requires

Outlook

The developed *Matlab* software modules permit the design and optimization of passive bearing components. The design of an inner damping via copper disks is also implemented. An inner damping does not suffice in any case to guarantee mechanical stability of the system. Currently, an outer damping cannot be simulated – further software releases will include the feature for designing outer damping components.
Some calculations concerning the tolerance sensitivity of magnet rings have already been done. In the next model release, the tolerance sensitivity will be included in the optimization calculations.
Up to now, the simulation results have been validated by FE calculations. The focus of future works will rest on the design and the construction of a prototype with respect to the validation of the software modules.

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Development of a modular micro-tribometer and a probe magazine for use in the field of UHV

Objective

Currently, only proprietary developments of institutes in the field of vacuum tribology measuring (range of friction measurement – micro Newton) are known. Therefore, the project "micro-tribometer" is to be developed in co-operation between IMMS gGmbH and the company TETRA.

Developement cycle and results

Two UHV chambers (measuring and magazine chamber) are connected. Thus, it is possible to measure and to replace probes when ultra high vacuum is switched on. In general, feeding of probes occurs by opening the second UHV-chamber.

View 1 shows the general assembly of UHV tribometer, consisting of two CF 100 double crosses including a UHV-lock, tribometrical system, and magazine. One chamber functions as a proofing chamber, and the second as a magazine chamber, with an integrated manipulation system for changing material probes. All mechanical and electrical connector units are commercially available.

The tribometrical unit is assembled to the CF 100 chamber. Positioning by means of a vertical moving translation stage makes it possible to replace the probe bodies using the manipulator.

The probe pockets will be produced by order of users. By activating the horizontal moving manipulators it is possible to replace the probes in the evacuated chamber.

The modular construction of the tribometrical system including the magazine and the manipulation system guarantees their application for a wide field of micro-tribological investigation.

In the following, parameters and functions of the tribometrical system are shown:

- Use under normal atmosphere and UHV;
- Realisation of pin-on-disc and reciprocation;
- Normal force resolution: 40µN;
- Tangential force resolution : 1µN;
- Normal force range (continuously variable): 0 to 5N;
- Tangential force range: 1µN to 25mN;
- Friction distance (reciprocating) : ± 0,5mm;
- Friction angle (pin-on-disc) : > 360°;
- Combination of friction bodies: ball/plane or ball/ball

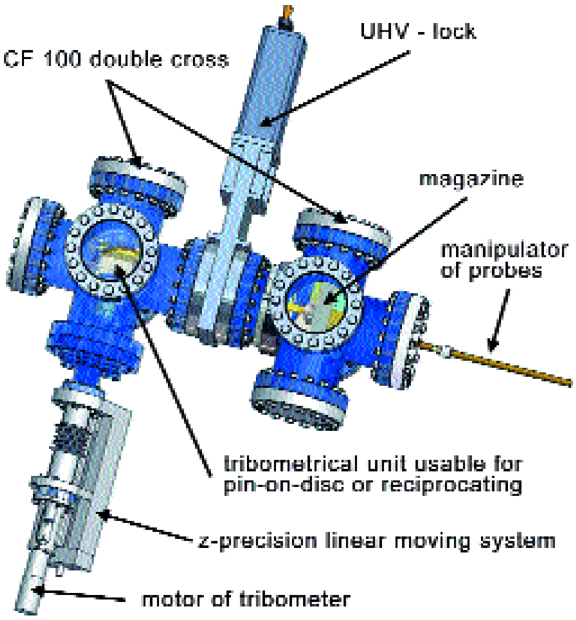

Fig. 1: system of the UHV chambers with tribometer and magazine

Outlook

The test results of the micro tribological system components are essential for further developments (readiness for start of production).

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DE 102 30 614.1-52

"Arrangement of reference marks on grid plates and reference sensors on the appropriate opto-electronic measuring head"

The invention refers to an arrangement of reference marks on grid plates and of reference sensors on an appropriate opto-electronic measuring head for detecting relative positions of a measuring head of a measuring machine, for example to the matching grid plate relative to the x- and y-positions and the contortion in the plane, where an arrangement of reference sensors (of the measuring head) is scanning the arrangement of reference marks (of the grid plate) arranged in the grid plane.
Such arrangements of reference marks and the appropriate measuring heads are essential parts of high precision measuring and processing machines operating in the micro- and nanometer range.

DE 103 27 505.3-52

"Material measure with integrated temperature equalization system"

For precision positioning tables and similar arrangements, measuring systems determining the respective table positions in the displacement plane are required, consisting of a grid plate with applied reference mark configurations and an opto-electronic mark detection system (measuring head).
Grid lines are applied to the grid plates in the micrometer range.
Temperature changes (usually temperature rises) of such a grid plate caused by drives and other energy consuming units and the resulting undefined expansions of the plate have adverse effects on the precision positioning accuracy of the table system, since now also the distances between the grid lines and the marks deviate from their standard measurements.
Such arrangements of grid plates and appropriate measuring heads are essential parts of measuring and processing machines operating in the micro- and nanometer range (see also DE 102 30 614.1-52).
A constant temperature of the grid plate can only be obtained by regulated cooling of the plate.
An internal cooling system for the grid plate is advantageous, since in comparison with external cooling, for instance by cooling air, the other system components are not cooled at the same time, or influenced (rather adversely) by uncontrolled air currents.

DE 103 26 978.9-12

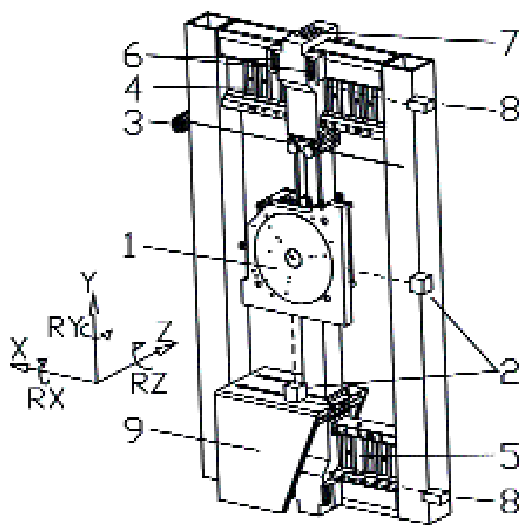
"Universal-joint shaft"

The invention refers to a universal joint with two swivelling axes connected to a graticule. The disadvantage of the previously known universal joints is that the frictional forces within the joint (roller or slide bearings) are too high for high-precision positoning tasks to be carried out by e. g. measuring and processing machines operating in the micro- and nanometer range.
The advantage of the patented universal joint is that the frictional forces between the cylindrical air bearings and the swivelling axes are identical to atmospheric friction, since the bearings are coupled only by the built-up layers of compressed air of the radial air bearing arrangements.
The air bearing universal joint is particularly advantageous for the design of swivel tables required for high-precision measuring, manufacturing, or assembly tasks.

US 6,639,225 B2

"Six-Axis Positioning System with a Zero-Magnetic-Field Space"

The invention refers to an arrangement for positioning substrates, in particular for positioning wafers, within a device that is provided for exposure of the substrates and/or for measurement on the substrates by means of radiation under high-vacuum conditions.



System Design

Also in 2003, the activities of the "System Design" department were focussed on the design and the realisation of complex embedded systems. Such complex embedded systems always have to be considered as a unity of both hardware and software and of communication components. Accordingly, the "System Design" department is subdivided into three divisions, each pursuing one of the mentioned topics. This involves not only maintaining the state of the art; moreover, an active development in the field is one of the general aims of the work. Within the topical area of "Digital Signal Processing and Industrial Sensor Applications", the key activities are in the field of hardware design methodology (SystemC, HDL), hardware modeling, and hardware realisation (ASICs, FPGA, PCB, SoC). The work within the field of "Buses and Networks" is devoted to questions of industrial communication, and in the third topic of "Embedded Software / Automotive Systems", we concentrate on the software for modern embedded systems, especially on software design methodology using model-based techniques (UML etc.), support for drivers and platforms as well as real-time control. In 2003 it became evident that a successful implementation of projects in the field of embedded systems always requires a combination of skills from all three areas.

Indeed, in 2003 not a single project has been accomplished without the synergetic work of all three topical areas. Out of these projects, two major ones were sucessfully completed. Within the project CAPSENS*, a method for smart-sensor development and the practical integration of a digital sensor-to-bus interface on the basis of IEEE 1451 were demonstrated to be successful. Another success was achieved in the project IntelliNet* where the development of a bus convertor concept (p. 26) on a self-developed EmLIN III platform has been accomplished. This new hardware version also supports modern rapid communication technologies such as USB 2.0 and IEEE1394b. The latter technology has been investigated thoroughly within the framework of a study which was assigned by the German Research Society for the Application of Microelectronics (DFAM). This survey proves the striking benefits and potential of IEEE 1394b in comparison with the established industrial communication technologies. Projects for the utilisation of IEEE1394b via optical fibres are currently being prepared. As a consequence of the insights gained by this survey, IMMS has become a member of the "1394automation e.V." society which is a consortium of German and Dutch companies. Its work aims at the support and proliferation of IEEE1394-based technology in an industrial environment.

As the general situation in the field of funded R&D projects has become worse due to the stressed situation in public finances, the "System Design" department actively participated in a number of project calls of the EU framework programmes. Project proposals and applications were elaborated and submitted in order to ensure the necessary level of research in the fields of activity, esp. for the development of advanced design methodologies for embedded systems. In contrast to this, there is a strong tendency towards industrial development in those projects aiming at actual realisation of embedded systems. Here, the challenge is to be successful both in free market and free competition. The fact that there were a number of such development projects also in 2003 proves that the department is capable of working under such conditions. In quite a number of such projects, OpenSource Technologies like eCos and embedded Linux were used as software platforms. Since summer 2003, the department as the representative of IMMS in the German Linux association LIVE e.V.. This is due to the fact that the "System Design" has rich expertise in integrating OpenSource technologies in customer-specific solutions and products. This has again been proved recently by porting the eCos platform onto two products of one partner as well as by the development of Linux board-support packages for PowerPC and PXA-processors for several companies. Further evidence is provided by the implementation of a cost-effective, Linux-based real-time control for the electrodynamic planar drive PMS100-3D which has been developed in close collaboration with the "mechatronic" department.

The department's "IMMS Concept Truck" comprises research results from nearly all of our fields of activity and serves as a mobile vehicle for demonstrating the capabilities of the team.

In 2003, there was a considerable involvement of students in project work. It turned out that the early integration of motivated students and their continuous promotion up to the diploma level is of invaluable benefit for both sides. Examples for such advanced work are subjects like "Hardware realisation of electromagnetic field computation", "Porting eCos and Linux to actual processors" (NIOS softcore or NetSilicon 9750) as well as "MATLAB-/Simulink-based code generation for Linux real-time control".

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Embedded Linux Board EmLIN

Objective

In the market segment of embedded systems Linux has been increasingly successful as an operating system. First of all developers are interested in the transparency as well as flexibility of the freely available operating system, by which they are pursuaded to trust in Linux.
In the area of embedded systems a main emphasis is put on the networking of the systems among each other. Depending on the requirements all different kinds of busses are used here. Here criteria are the achievable data throughput, interference immunity and failure safety or real-time requests. Today busses are used in application areas for which they originally were not intended. The 1394/FireWire bus developed for video applications is in industry meanwhile being used for control functions.
If only two different busses are intended to be linked with each other, it is important to consider the necessary conditions of the hardware as also of the protocol used.
Exactly this point represents an attempt for the development of a modular bus converter system. Most important aim at the realization of the idea was the conncection of different busses to the Ethernet. The connection to Ethernet is of great importance, because, on the one hand, almost every computer has meanwhile been networked and, on the other hand, the Ethernet protocol is offering several possibilities of data transmission.

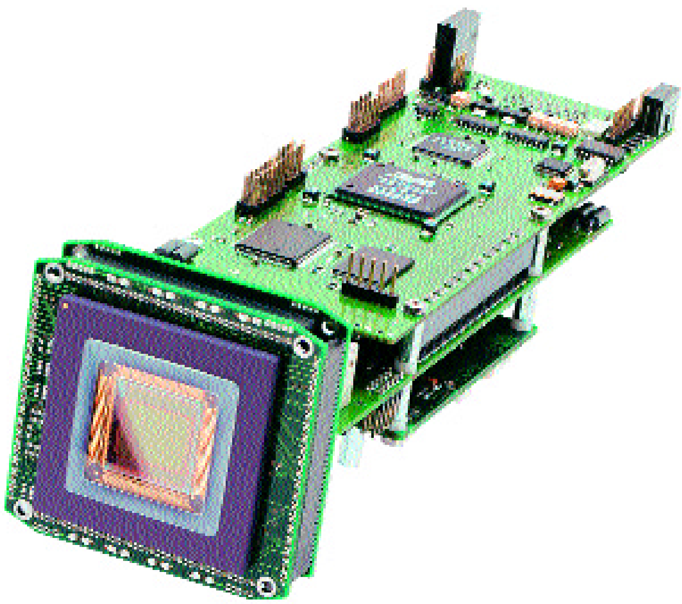

Fig. 1: reference board
Source: Techno Team

Research process

Within the development of the modular bus converter the set-up took place on the reference board [1], developed by us, on the basis of the Net+40 by Netsilicon. Owing to that the experiences made at porting Linux to other processors as well as the driver development could be extended. At first the result of that was a modular reference design on the basis of a more state of the art processor Net+50. Into existence came modules for the processor as well as for the USB and CAN bus. In addition the board was equipped with a FPGA, in order to test and apply IP components developed in the house. An example for that has already been discussed in [2]. The third and for the moment last step was the miniaturization and overhauling of the hardware developed. The result of the development is shown in figure 1.
Already in the concept phase it was taken care that the platform was designed as open as possible, on the basis of which the interfaces were flexibly configurated. The interface of the IO cards was taken from the open DIMM-IO standard by Kontron, which corresponds to the well-known ISA bus. The processor interface is developed in such a way that customer-specific processor modules can quickly and easily be developed and implemented.
The software development took place in parallel to the hardware development. Started was on the basis of the reference design with a Linux-kernel 2.4.6, which was later replaced by a 2.4.10 kernel.
Porting of the 2.4.17 kernel took place by the introduction of the Net +50. Currently, the kernel version 2.4.20 is used on the Net ARM processor. The driver versions developed in the house for different busses are continuously adapted to updates and new conditions.
Besides the porting and the driver developments various software has been programmed for the client server communication.

Results

In practice the bus converter EmLIN is used as Ethernet-CAN Gateway in the IMMS Concept Truck in connection with a WLAN interface. Here the opportunity is given, to access or manipulate the data of the CAN bus, widely used in automotive engineering, via a standardized wireless connection. It must be pointed out that the software used for the evaluation and control in EmLIN and alone one PC is

needed for the visualization of the data represented with a conventional Web browser.
The EmLIN processor module is already used in an industrial camera by Technoteam, Ilmenau. Here too, EmLIN is used as Ethernet Web browser for the control and adjustment of the camera and its parameters. The camera itself is connected to EmLIN via a 32Bit data bus interface, which has been realized in a FPGA.
In the course of the Linux porting and as a contribution to Linux, a Linux distribution for embedded systems has in addition been developed, which in the Internet can also be loaded by other users.

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[1] Annual report IMMS 2001; S.21; Embedded Linux
[2] Annual report IMMS 2002; S.10; Serial ATA - Implementation in FPGA for embedded systems

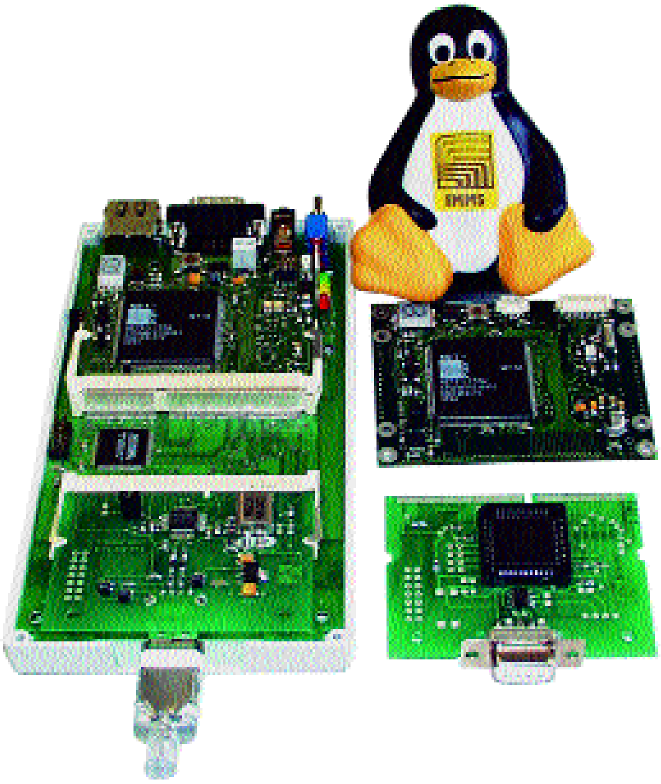

Fig. 2: EmLIN 3 platform

Signal processing and bus gateway for capacitive sensors

TMWFK, B609-01030

Objective

As part of of the joint project “Capacitive Sensor Transducer” (CapSens) funded by the TMWFK, a digital signal conditioning for non-linear sensors and an all-purpose sensor-bus interface (Fig. 1) were developed.
The non-linear signal of third order should be linearized and temperature compensated by a suitable signal conditioning algorithm.

The fix-point model was designed using the Xilinx-block set, and synthesizable VHDL-code could be generated with the Xilinx-System-Generator. To ensure that the resulting error is within the required limits, the conditioning algorithm was developed with methods of regression.

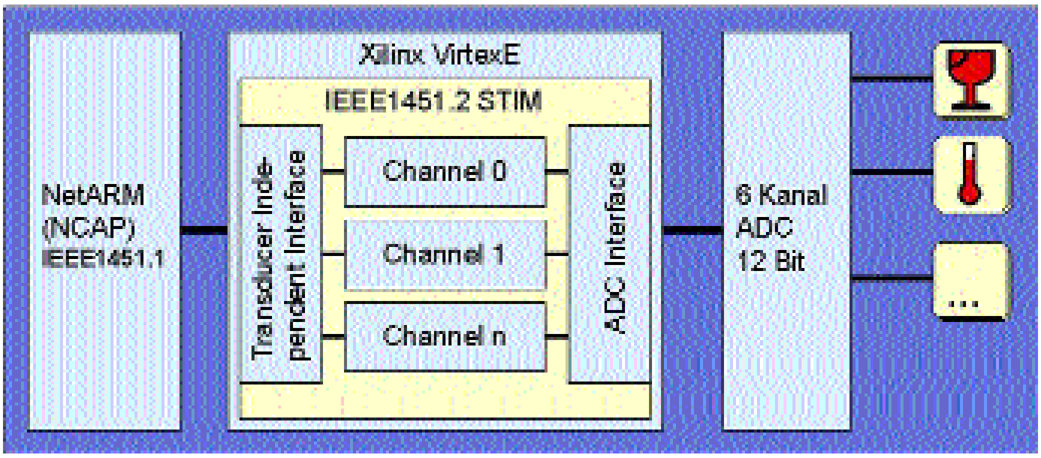

Fig. 1: sensor interface according to IEEE1451.2

Progress and status of research

The CapSens signal conditioning algorithm was completly modeled with a high level tool. Simulation and modeling of the humidity sensor was done with Matlab/Simulink. The digital signal conditioning algorithm for temperature compensation, linearisation (s. Fig. 2) and Full Scale Offset calibration (FSO) was designed in two different models, one for floating-point calculation, and the other as a fix-point arithmetic model. The floating-point model was for verfication purposes only.

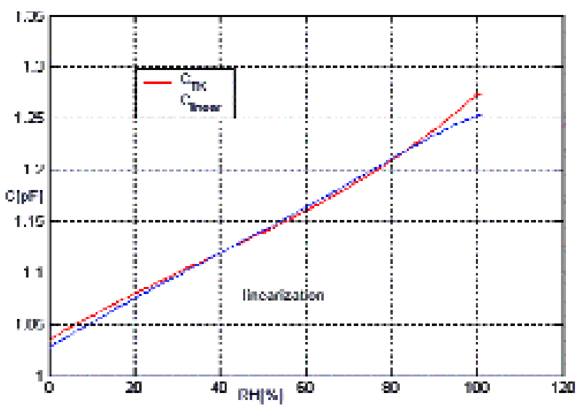

Fig. 2: linearised curve

The sensor-bus interface was designed according to the standard IEEE 1451.2 and represents the link between the analog sensor on the one hand and the used bus system on the other hand. The interface provides a subset of channels for each sensor. It is possible to store one datasheet per channel, e.g. containing the calibration parameters.
Each channel has a ‘Function Block’ which can contain a special signal processing, e.g. linearisation (s. Fig. 3), temperature compensation and FSO-calibration. By exchanging these ‘Function Blocks’, the system is modifiable for different sensors.

Outlook

The characteristic curve of a capacitive sensor is linearised, temperature compensated and FSO-calibrated with the devoloped signal processing. The sensor data is now available via the new sensor-bus interface for further applications.
A modular prototyping system was designed to display these results. Part of the system demonstrates the signal processing and the bus gateway. The analog part (capacitive transdu-

cer and ADC) was realized externally and can be connected to the digital part.
For testing purposes, a commercial ADC was used. As soon as the chip prototype of the ADC proprietary to IMMS will be available, it will replace the commercial one.

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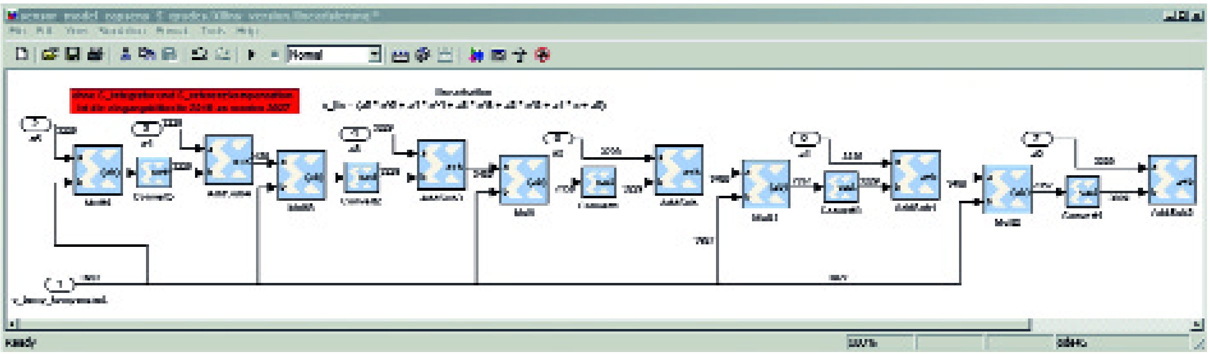

Fig. 3: linearisation model with Xilinx block set

A flexible hardware/software platform concept for mobile data communications applications

Objective

Users and manufacturers currently pin great hopes on the growing market of mobile data communications, particularly on M2M technologies. M2M (machine-to-machine) stands for data communications of machines, vehicles, containers, automations-either among themselves or with central control systems. The most important areas of application include transport and logistics, point-of-sale monitoring, security technology, and remote sensing and maintenance. Market studies suggest that the number of devices communicating via GSM or GPRS networks will exceed the number of human users in approximately two years. Yet in order to achieve the desired benefits such as higher productivity, cost reductions, and accelerating work flows as well as making them more flexible, both appropriate terminal devices (so-called M2M terminals) and their efficient integration into higher-level IT structures are required.

In response to this situation, IMMS has been focusing on innovative hardware and software technologies for mobile data communications devices in the course of a R&D partnership with *Falcom Wireless Communications GmbH* for some time. As a result of this cooperation, e.g., a flexible platform concept (Fig. 1) for smart wireless communication devices (SWCDs) has been developed, which has successfully been deployed in a number of *Falcom* products.

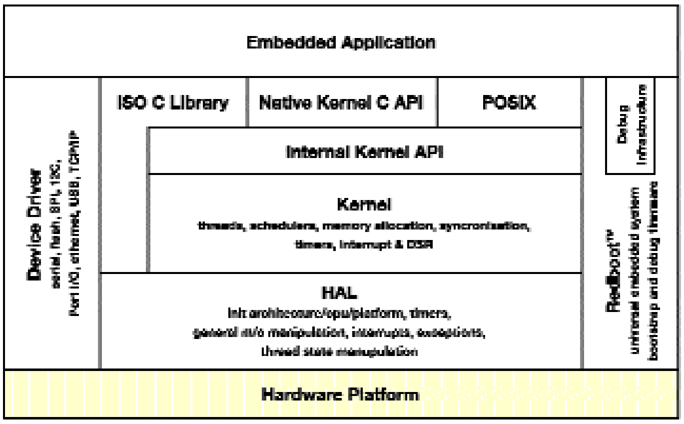

Fig. 1: the hardware/software platform concept

Results

Outstanding attributes of the new hardware/software platform F35-XXL-SI (Fig. 2) include the comprehensive application of open-source software technologies and an open hardware concept which has been engineered for adaptability and extensibility. The software platform consists of the open-source operating system *eCos* and a middleware/application library based on it, which provides a powerful interface optimized for typical data communications applications. The hardware platform primarily

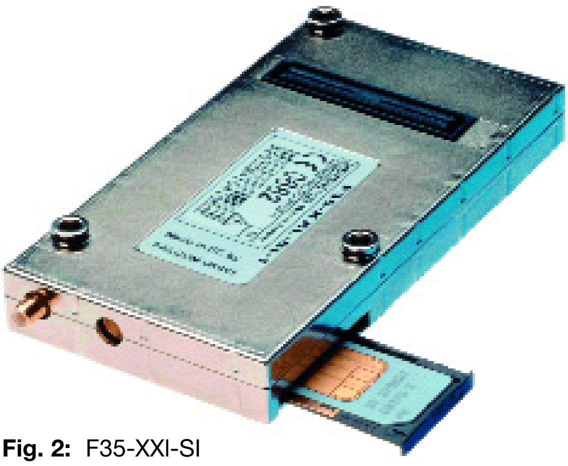

Fig. 2: F35-XXl-SI

consists of a 32-bit micro-controller, comprehensive peripherals and the core components GSM/GPRS modem and GPS core. The platform is completed by open-source development tools based on GNU/Linux, which allow users to inexpensively start development projects of their own. The prototypes created in the course of the cooperation among IMMS and *Falcom* have meanwhile been transferred to series production as a result of the development of several products.

The focus of the R&D activities with *Falcom* is now on the systematic extension and refinement of the existing hardware/software platform, its porting to new hardware platforms, and the consequent adherence to the platform strategy in the area of application software. Thus, for example, the hardware platform has been extended by a keypad and an LCD display, and the corresponding software drivers have been integrated into the software platform. These extensions will allow for a future use of the platform in MMI-oriented (man-machine interface) applications, such as mobile hand-sets. Another part of the project has dealt with porting the software platform to even more compact hardware platforms. In conse-

quence, e.g., the remaining resources of a GPS core could be used to run the real-time operating system *eCos*, the middleware based on it, and a typical M2M application. In cooperation with the manufacturer of the GPS core, a technical solution has been designed and realized which allows for the integration of proprietary, binary-only GPS firmware. In the course of this, the advantages of the *eCos* license model have become particularly noticeable by explicitly permitting the combination of open-source and proprietary software (without having to disclose the latter). First prototypes (Fig. 3) of the *eCos* STEPP platform described above could already be tested successfully. Thus the foundations for a new compact and inexpensive data communications solution to be produced by *Falcom* have been laid.
For *Falcom*, the platform strategy has proven an adequate response to current and future challenges of the market of mobile data communications devices. It has become obvious that the application of software platforms and software architectures based on these contributes to more efficient design processes. Development environments can be standardized and initial training periods can be shortened. Besides, the application of current concepts in software technology have allowed us to show that using product line modelling, a high degree of reuse in application development can be achieved, which in turn reduces development time significantly. The interest in this topic at workshops and conferences confirms the relevance of this work.
Regarding the hardware, there are positive effects of the platform strategy as well. For example, *Falcom* managed to derive entire product lines based on few uniform hardware platforms, thanks to which manufacturing and development can be done much more efficiently.

Outlook

The platform concept has proven in practice. In the future, it will be important to further extend and improve this successful concept in cooperation among IMMS and *Falcom*, in order to continually adapt to the booming yet hard-to-predict market of mobile data communications.

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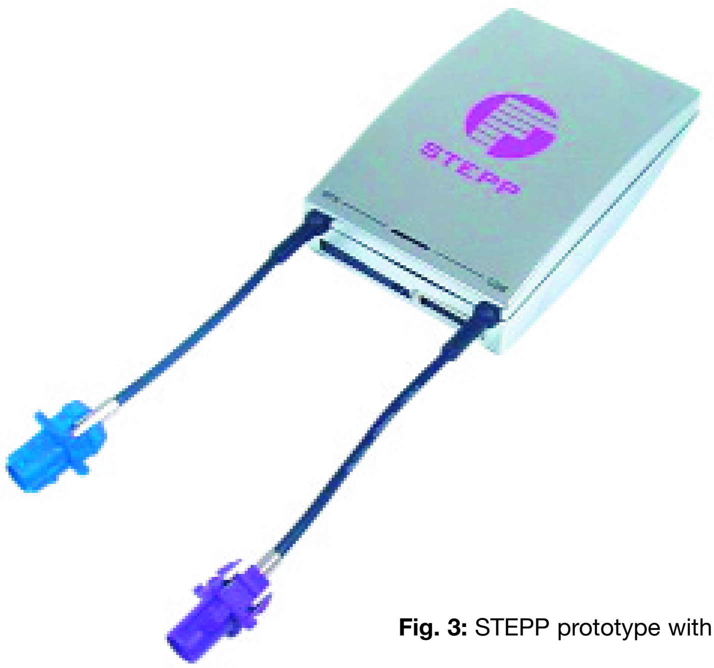

Fig. 3: STEPP prototype with GPS core

Microelectronic circuit engineering

In the year of 2003 the research work on microelectronic system solutions and SoCs could in the institute branch Erfurt be extended and intensified through the realized move into the new application centre for microsystem technology “Anwendungszentrum Mikrosystemtechnik (AZM)” In 2003 the infrastructure was considerably extended regarding measuring and computer equipment.
The year of 2003 was characterized by the growth of the share in industrial contract research on the basis of the competences achieved and the efficient equipment.
Great industrial interest was paid to the achieved level of performance within the application of innovative design methods of the formal verification, symbolic analysis, design centering as well as system simulation of mixed-signal systems on the basis of behaviour description languages. In circuit engineering above all competences on transimpedance and sensor amplifiers, HF-circuits, high-temperature circuits, innovative sensors (optic, magnetic, micro systems) and on system concepts (ADCs, signal processing) were in demand. By the use of new design methods the following improvements were achieved:

- Provable faultlessness of digital and mixed-signal systems through the use of constraints and formal verification
- Increase in the robustness of analog systems towards variations in the operation conditions and technological tolerances
- Yield optimization for analog circuits
- Exhausting technological conditions through optimized circuit design
- Reducing design times and increasing design effectiveness
- Innovative, optimized system architectures
- Improvement of the achievable specification parameters

In 2003 phase I of the MEDEA*/BMBF* sponsored projects ANASTASIA* (s. p. 33 and 38), SPEAC*, VALSE*, ASDESE* were concluded with summary reports. In the second half of the year the continuation projects of phase 2 were started for the a. m. projects (except ASDESE). Within these projects and the EU-project ATHIS* (s. p. 37) an international cooperation with Italien, French, Austrian, English, Swiss a. o. research partners took place. Further projects were prepared for a start in the year of 2004. Finished was also the DFAM-DSP-project, which was sponsored by the AIF.

In 2003 main emphasis was put on:

- **Area-overlapping activities**

Behaviour models for circuit blocks; design and characterization of technology test structures; work on design-kits and design-check; optimization of circuit blocks as OPVs and band gaps

- **System on Insulator (SOI)**

Work on design-kits and libraries; extension of activities on high-voltage and power amplifiers as well as power switches with supervision of critical parameters, development of EEPROMS and RAMS plus BIST-concepts for theses circuits; ADCs and DACs for SOI-circuits with increased temperature range (220°C) and high reliability requirements; research work on new technology variants and new sensor concepts (magnetic layers); automotive applications (integrated 42-V-SOI-power supply with linear and PWM-regulators)

- **Precision analog circuits**

Universal SC-sensor amplifiers; work on ADCs (noise improvement, new structures) and detail circuits as band gaps; offset compensation; compensation of the non-ideal behaviour of circuit blocks;
Correction circuits as well as work for partial automation of design work (PCELLS for capacity arrays); circuit concepts for U/I and I/f-converters and Sigma-Delta modulators; analog circuit blocks at reduced operating voltages (3.3V) on the basis of 0.35-μm-technologies

- **Opto electronics**

Research for the extension of specification parameters (noise, realization of higher transimpedancies, increased sensitivity for blue light; realization of TIAs in an extensive range, high linearity (phase, group delay), stability securing, extension of the dynamic range of the TIA, switch-selectable amplifiers, adjustable transimpedancy amplifiers; development of integrated receive circuits and VCSEL-driver (600-800nm, 655MB/s, adaptation to multi-mode fibers) as basis for low-cost-transfers in the environment of automation solutions and automotive networking

- **HF-circuits**

Research work on LC-VCOs; realization of integrated inductances; PLLs; innovative FSK-demodulator circuits.

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*s. page 52

Optimal sizing of analog circuits with WiCkeD

BMBF, 01M3068H

Objective

After selecting a circuit topology the sizing of components is a fundamental part in designing analog circuits. Sizing determines the electrical parameters of the components and so the electrical behaviour of the circuit. In MOS-circuits sizing primarily regards the widths and lengths of transistors and the dimension of passive components (resistors, capacitors). The given specification of a circuit is usually so challenging that only with an optimal sizing all achievement parameters are fulfilled.
In addition to the design parameters the behaviour of the circuit depends on statistical process parameters and operational parameters:

Design p.	d(W,L)
Statistical p.	s(t_{ox}, N_{sub},V_{th}, ...)
Operational p.	Theta(V_{dd}, C_{load}, I_{bias}, Temp)

The optimal sizing for mean values of statistical and operational parameters is called nominal optimisation. To get a maximal yield, we must ensure the specification requirements also with certain variations of process parameters. This is obtained by design centering. Because of the complex interdependencies between parameters and circuit behaviour the optimization is possible with computer aided tools only.

WiCkeD

A new tool for sizing and design centering is "WiCkeD", developed by MunEDA, a spin-off from TU-Munich. WiCkeD was made available to IMMS within the scope of the research project ANASTASIA2 .
WiCkeD presents the user a graphical interface to start all analysis and optimizing functions. Every step is represented by a symbol and is connected to a set of design parameters. If a sequence of steps does not yield acceptable results, the user can begin a new sequence at an arbitrary node. So a tree is generated, representing all user's steps by its nodes.
The parameters of any node may be written back to the original circuit using the back annotate function.
Several symbols in the main window represent

- Parameter influence analysis
- Simulation node
- Nominal optimization
- Mismatch analysis
- Design centering

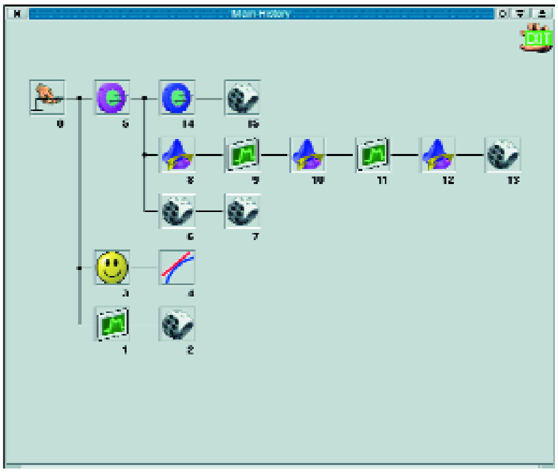

Fig. 1: main window of WiCkeD

Constraints

To reduce the computation time for optimisation and to avoid useless solutions, sizing constraints are introduced which minimise the number of parameters and shrink the search range. WiCkeD has an automatic constraint generation based on rules, assigned to circuit structures. Therefore a structure recognition must be done before the constraint generation. The following structures are currently recognised:

- Current mirror
- Level shifter
- Voltage reference
- Differential pair

For each structure a set of rules exists, for example the saturation conditions for current mirrors.

Feasible Solution

A prerequisite to further optimisations is a feasible solution, for which all constraints are satisfied. If the starting parameter set violates any constraint, WiCkeD can automatically compute a feasible solution.

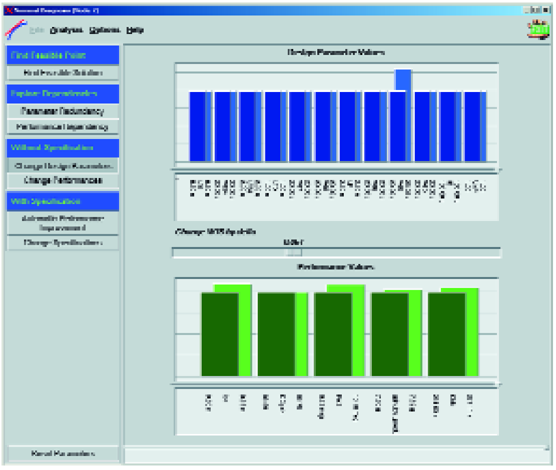

Fig. 2: nominal optimisation

Nominal analysis and optimization

The nominal analysis graphically shows the influence of design parameters on the performance data of the circuit. After selecting a parameter in the upper part of the window, the user may change continuously the parameter value with a slider. The effects of parameter changes to performances (bandwidth, gain) can be seen immediately in the lower part of the window. Contrariwise the user can select a performance, change it with the slider and can see how the design parameters must be changed to get a better performance.
During the nominal optimization the tool changes the design parameters automatically until all given performances are satisfied or the maximum count of iterations is reached.

Design Centering

For yield estimation the “worst case distance” is defined for each performance as the shortest distance between the nominal point (where statistical parameters S have their mean value µ) and a specification boundary. Beyond the specification boundary the performance value does not satisfy the specification because of large process variations.
The yield is optimal when the smallest worst case distance has maximum value. This is leading to a balanced distribution of the worst case distances.

Cadence Interface

With the WiCkeD Cadence Interface (WCDI) the design data of the Cadence Design Framework can easily be transferred into WiCkeD. All circuit’s design parameters (W,L) should be in parametrical form and all performances (bandwidth, gain, slew-rate,...) should be defined as output data in Analog Artist. Further functionality of WCDI is the constraint generation and the back annotation.

Results

WiCkeD was successfully applied to optimisation of circuits in the X-Fab technology xb06. For example an op-amp, which was manually optimised over the time of 4 weeks, was optimized with WiCkeD in one day and yielded better results than manual optimisation.
Unfortunately, there is no statistical data for xb06, so we can only do the nominal optimization.

Outlook

IMMS created the Spectre-simulation models for the SOI-technology xi10. So WiCkeD can be used for circuits in this technology. Furthermore the nominal optimization and design centering will be applied to circuits in the new xc035 technology. IMMS offers the optimisation with WiCkeD to all industrial partners.

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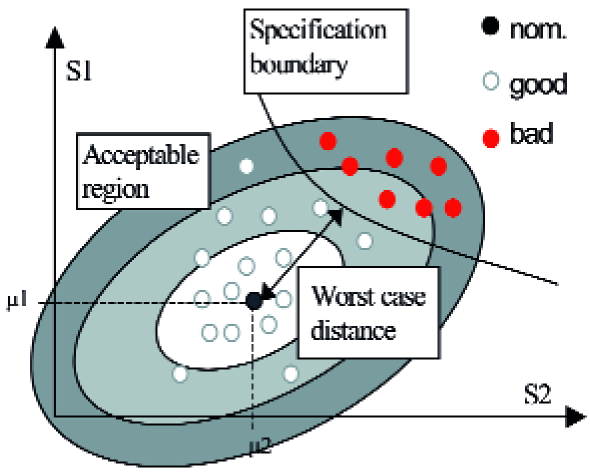

Fig. 3: worst case distance

Transmitter-IC for the 868 MHz ISM-band with fully integrated LC-VCO

Objective

There is a rapidly growing need for wireless applications covering a variety of license-free industrial-scientific-medical (ISM) and short-range-device (SRD) bands. Complete transmitter or transceiver solutions that require only a few external components for the transmit part have already existed for a while. Very often they employ VCOs based on a ring oscillator topology. The required spurious emission limits of the respective standards, e.g. EN 300 220-1, together with the increasing demand for narrow channel spacing, low FSK deviations and increasing output power, impose great demands on the phase noise performance of the VCO. These requirements can hardly be fulfilled by ring oscillator-based VCOs.
One approach for solving this problem is to use an LC-based VCO with an external inductor. Those VCOs suffer from increased LC tank parasitics, the risk of multi-mode oscillations, and an increased pin and external component count. These disadvantages can be avoided with a fully integrated LC-VCO.
This project was realized in cooperation with MELEXIS GmbH (Erfurt).

Results

Based on previous research activities with integrated inductors and LC-VCOs, a fully integrated LC-VCO for the frequency range around 868MHz was designed. Integrated inductors for these relatively low frequencies need a considerable chip area. For this reason, a VCO topology was chosen that contains only one inductor.

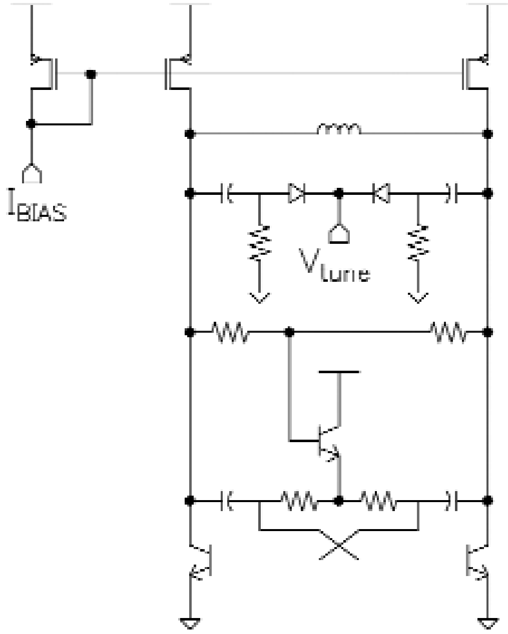

Fig. 1: schematic of the VCO core circuit

The following parameters were reached:

- Supply voltage range 2.2V to 5.5V
- Current consumption of the VCO core 1.35mA
- Center frequency 860MHz
- Tuning range 150MHz
- Phase noise –80dBc/Hz at an offset frequency of 10kHz
- Layout area 0.48mm^2

The critical parameter phase noise was improved by more that 25dB with regard to the present VCO. The other parameters are comparable. However, the LC-VCO occupies approximately the tenfold layout area.

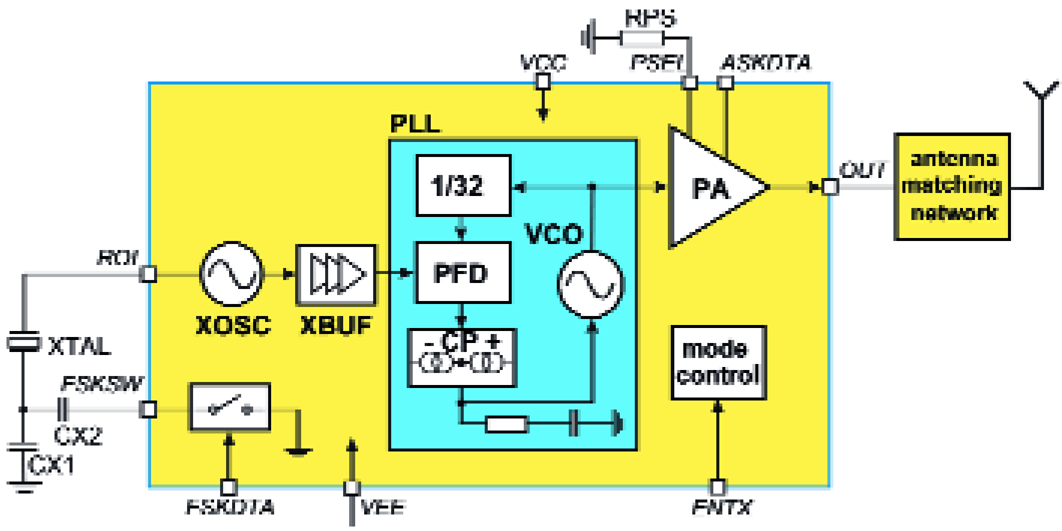

Fig. 2: block diagram of the Melexis transmitter IC, with external circuitry

This VCO was integrated into Melexis' existing FSK/ASK transmitter IC for the 868MHz ISM band. Because of the improved VCO phase noise, the bandwidth of the PLL was reduced from approximately 700MHz to 200Mhz. This allows for a considerably improved attenuation of the charge-pump noise and the reference feed-through. The output power of the power amplifier was increased. Now a greater transmitting power is possible, at the same level of spurious emissions.

Outlook

The IC is currently being processed. After characterization, the next logical step is the realization of a multi-channel transmitter IC. In a multi-channel transmitter, a fully integrated LC-VCO is one of the key building blocks.

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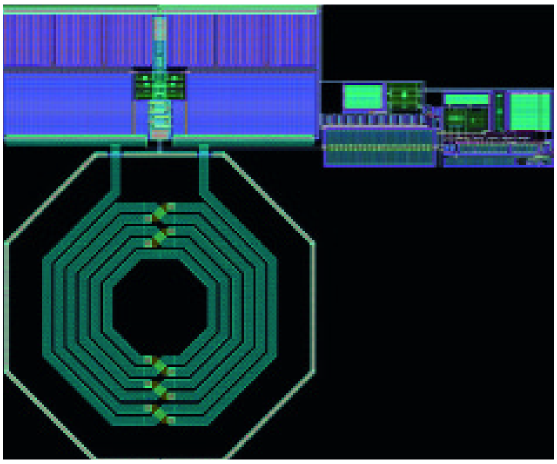

Fig. 3: layout of the VCO as it is used in the transmitter IC. The VCO core circuit is located above the inductor.

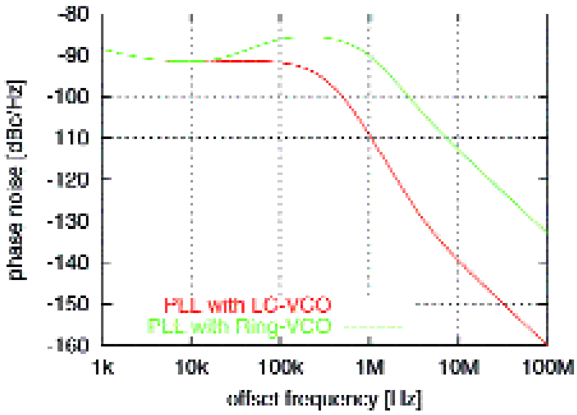

Fig. 4: improved PLL phase noise with LC-VCO (simulation)

Development of memories for automotive applications in SOI

EU, G1RD-CT-2002-00729

Objective

Within the EU-development project ATHIS (**A**dvanced **T**echniques for **Hi**gh temperature **S**ystem-on-Chip) static random access memories (SRAM) have been developed by the department SOI since the start of the project in April 2002. They are planned to be used in the Multi-Chip-Modul, to be developed as the project aim, for injection control in diesel engines. The project period is 42 months. The project partners are coming from Belgium, Italy, Spain and Great Britain.

Course and state of research work

In the specification for the ATHIS Multi-Chip-Modul two different memories are found. A 256x16 Bit Single Port SRAM for the storage of program codes and a 32x16 Bit Dual Port SRAM for intermediate storage of measured data needed for injection control. Both memories are realized with the same basic modules (cells, drivers, sense amplifiers), the differences are merely found in structure and assembly. In order to have test objects available for both memories, 32x16 Bit test memories since the start of the project in April 2002 were designed and fabricated since the start of the project in April 2002 at the begin of this year. Figure 1 shows the layout of the Dual Port RAM. In the second

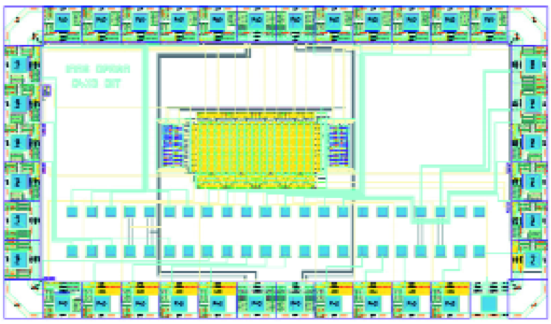

Abb. 1: layout of the Dual Port RAM

half of the year both memories were subjected to a functional test at room temperature. In this test the possible clock rate as well as the vulnerability to bit errors was tested. All tests had positive results. The read-out of the chess board tests for the detection of bit errors is shown in figure 2.

Result

As soon as the characterization of the memories is finished, memory chips are available as a first intermediate result from the project work SRAM,

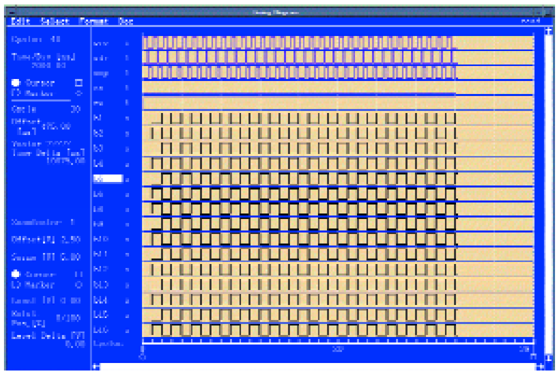

Abb. 2: chess board test without bit errors

which can be used in various application areas. In particular their suitability also for the extended temperature range distinguishes them from products available up to now.

Outlook

In the first few months of the coming year it will at first be the SRAM memories that are characterized over the complete temperature range of –40 to +220 degree Celsius. In parallel the digital circuit with integrated memory, developed for the project, will be finished and produced. From the test results of these circuits the conclusions shall then be drawn for the last redesign of the circuits planned in the ATHIS project. The circuit elements improved that way shall then be assembled until July 2004 to a complete circuit system for injection control of diesel engines. With that the design work of the project is finished.

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Design of a power supply for 42V automotive applications

BMBF, 01M3068H

Objective

In January 2000 the EU-project ANASTASIA+ (**Ana**log Enhancements for a **S**ystem **t**o **S**ilicon **A**utomated Design) was started, in which the IMMS takes part as a partner. In 2003 phase II began. Besides the IMMS institutes and companies from the Netherlands, France, Austria, Italy and Germany have been participating. Aim of the project is, to develop methods for the automated design for applications in the mixed signal area and to realize them in the form of demonstrators.

The efficiency of new EDA-methods from the other work packages is to be proved in a step down and a linear regulator in SOI-technology. The methods of behaviour simulation with VHDL-AMS developed in the project, are applied to both regulator types. The symbolic analysis is demonstrated by means of the linear regulator only. It is planned to apply design centering to both circuits, in order to be able to demonstrate the design safety achievable with that. Both circuit elements are designed in such a way and are tuned to each other that a uniform circuit block can be realized for a power supply.

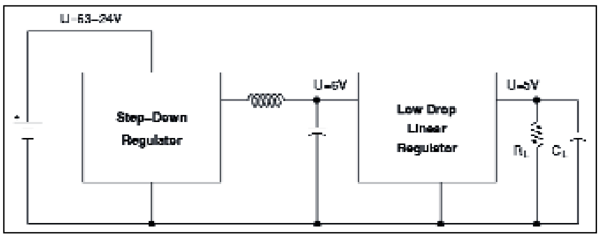

Fig. 1: block diagram of the 42V power supply

Course and state of research

The work on the WP4.3 "reusable block 42-V-power supply with specification and measuring report" supplies the knowledge for the integration of the SOI-models into the CAD-tool environment, as well as for the methodology of the block design of HV-designs at the increase to 42V onboard power supply voltage. By the implementation of the tools "Analog Insydes" for the symbolic analysis at stability problems, it is shown that with the extension of the existing CAD-tools a practicable way is feasible with such special solutions and the effectiveness of design work is definitely increased.

The expositions on the design method for mixed-mode-designs are directly based on the results of the work within WP3.1 (circuit synthesis, sizing and design centering): "results of the application of the symbolic analysis for migration of circuit structures; comparison of models with measurements".

The power-supply is designed for the 42V specification. The load current may be 150mA. Planned is an excess temperature and an overcurrent protection. By the use of the SOI-technology a large temperature range is produced, in which such circuits may be used. The power supply consists of a step-down-regulator with post-connected linear regulator. At the simulation and the subsequent realization of the step-down-regulator in the layout Analog Insydes, Advance MS, Cadence spectre (with verilogA models), Cadence Virtuoso Layout Edito were used, in order to guarantee a good dimensioning under consideration of all stability conditions. This resulted in an improved circuit design for a PWM as part of the step-down-regulator.

Outlook

As the next step for a complete power-supply the realization of the linear regulator as a low-drop-regulator is planned. The methods from WP2 are used for the structural design of the power-supply. In order to guarantee an improved robustness as well as very good PSRR over all corners, the tool wicked (WP3, s. p. 33) is used. With that a new way of "fast prototyping" is demonstrated.

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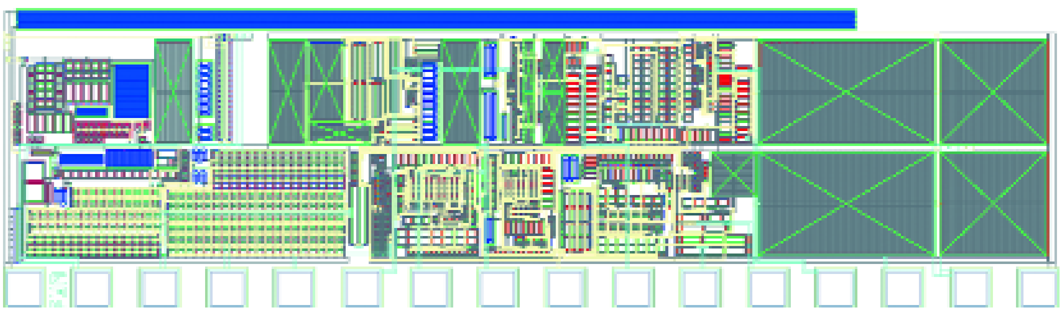

Fig. 2: layout of the PWM

Embedded systems in Simulink

Objective

The market for embedded systems will grow rapidly in the coming years. Furthermore, the portion of the software in the overall system is increasing continually. Therefore, it is necessary to realise a common development environment for hard- and software. A co-simulation between a graphic system description and a microprocessor simulator was examined in the research project SpeAC (Medea+ project A508) in co-operation with Melexis GmbH.

Research process

In the first phase of the project, the integration of a software simulator in Matlab/Simulink was examined and realised as a prototype. As software simulator, the Melexis MLX16 (a 16-bit microprocessor) was used. The simulator integration was improved during the course of the project, taking into account experience from practical applications. For example the gasoline pump control developed last year was refined.
With the experience gained from the MLX16, an additional Melexis software simulator was integrated into Simulink.
The simulator is the Melexis MLX4 (a 4-bit microprocessor), which is used in automotive electronics. An important feature of the MLX4 is the fact that it can process 2 software tasks in parallel (dual task CPU).

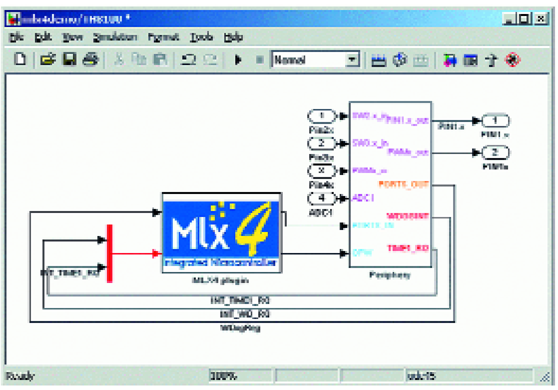

Fig. 1: view of the MLX4 in Simulink

As an application example a LIN slave controller was realised in Simulink, however without the LIN bus. This chip has several inputs and outputs, which can be read and modified by the LIN master. Task 1 of the MLX4 controls the LIN bus. Task 2 reads the inputs into the data memory at cyclic intervals and changes the outputs according to the values of the data memory. Existing software for the start-up of the chip could be simulated with the model. It could be proved that the software for task 2 functions correctly.
Configuration tools were developed for both software simulators to ensure a simple use of the MLX4/MLX16 processors in Simulink.

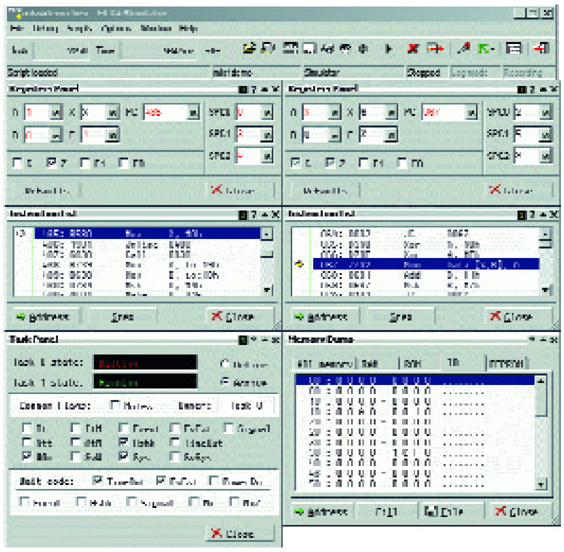

Fig. 2: screen of the MLX4 simulator

Outlook

A SystemC model of the MLX16 is being developed. A higher simulation speed is expected from the use of an interface optimised for simulator coupling.
A window lifter control system with the MLX16 was selected as an additional application project for the conversion into Simulink.
It is planned to transfer this methodology into the established design flow of Melexis.
Another goal is the integration of the LIN bus into the simulation to find a suitable level of abstraction.

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Design of a cascaded 8 bit flash analog digital converter

Objective

Within a practical training the redesign of a two-stage 8 bit flash anlag digital converter was carried out, which in the first design showed a coding error. This error had to be retraced and detected under Cadance. Subsequently, the error was configurated, the concept of the ADC slightly improved and the complete design flow used for a mixed signal IC. The design flow contained simulation of the circuit diagrams, conversion into layout, verification of the layout, simulation of the recognized layout and eventually the generation of a measuring board as well as measurements at the realized IC.

Course of research work

The English expression “flash” is used, because this kind of A/D-converters is working very quickly (lightning-fast). In figure 1 the principle of the ADC is shown. The converter is set up from a number of voltage comparators working in parallel. When the input voltage UX reaches the value of the individual reference voltage Uv,

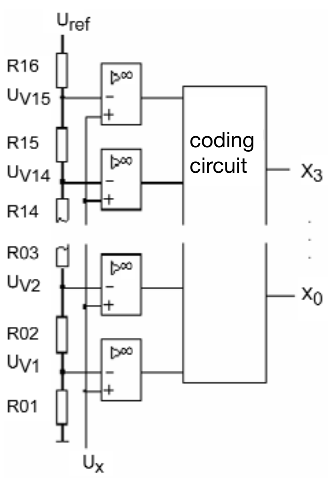

Fig. 1: flash converter principle

the comparator connects through. For a four-bit-converter 15 comparators are needed. An eight-bit-converter already needs 255 individual comparators. After that a coding circuit is needed, in order to convert the put out “thermometer code” into a binary result.
The 255 comparators in case of a 8 bit converter mean an enormous expenditure of circuit engineering work. The space requirement is very high. In this place the 2-stage converter starts being active. In principle it consists – in case of an 8 bit converter – of 2 cascaded 4 bit converters. The first 4 bit are responsible for a coarse resolution and build up the reference

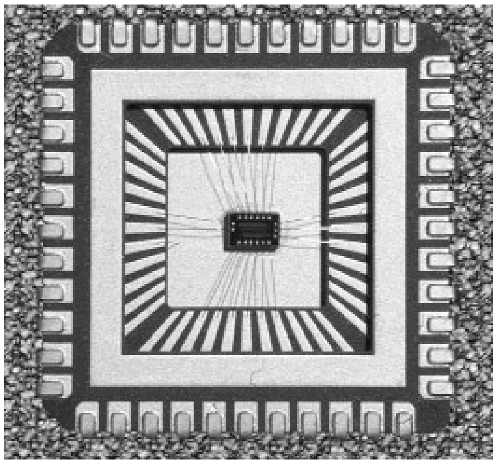

Fig. 2: bonded component in open casing

voltage for the 2.4 bit converter, which takes on the fine resolution. The fine resolution is connected to the individual voltage range of the coarse resolution. By this measure the number of comparators required is reduced to 30, which means a definite reduction in layout surface. New at this converter principle is that the conversion is taking place in one step. Therefore, the principle of a flash converter has not been violated. A problem is, however, the provision of correct reference voltages via resistor chains connected in parallel.
In the course of the redesign possible changes in the concept of the two-stage flash ADC were investigated, in order to first of all counteract the problem of the incorrect reference voltage. As already mentioned this was, on the one hand, caused by the voltage drop at the switches for fine resolution and, on the other hand, by the individual parallel connection of the fine resolution to a resistor of the coarse resolution. Especially in the coarse resolution the parallel connection led to great deviations from the set reference voltage. In order to counteract these deviations the first attempt was, to connect additional parallel dummy resistors. The dummy resistors have the same value as the total resistor chain of the fine resolution. Like that the resistors are always under the same load in coarse resolution, as either the fine resolution or the dummy resistor is connected. Owing to that the reference voltage should no longer show any variations. It could be unfavourable for later matching that the resistors for coarse and fine resolution consist of different types and sizes. At the same time the switches had to be optimized, which were designed as CMOS-transfer switches. In fig. 3 the layout of the flash ADC is shown. Great attention was put on the resistor chains for the reference voltage. Like that the resistors are arranged as

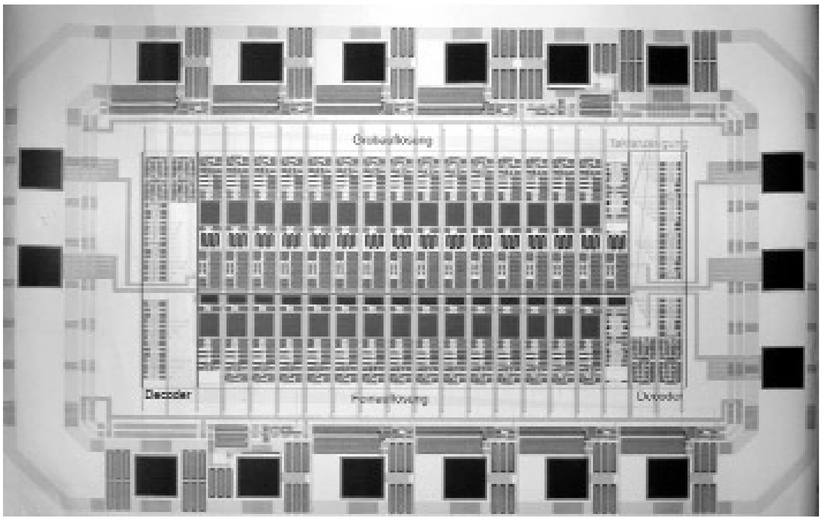

Fig. 3: layout of the flash-ADC

tightly as possible to each other and without long leads. Also the lead to the two bonding islands are arranged as direct as possible and of the same length, in order to avoid dissymmetries. Apart from that the signal paths within the IC were kept as short as possible. The IC was manufactured at the X-FAB Semiconductor Foundries AG and put into a 44-contact ceramic package (s. fig. 2).
In order to be able to measure the flash ADC, a suitable test board was designed providing the

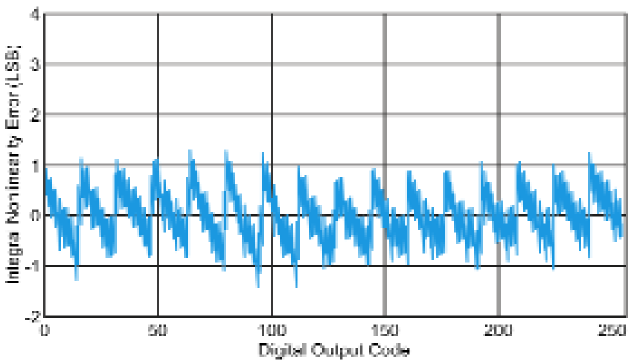

Fig. 4: INL of the flash AD-converter

required connections for the operating and input voltages as well as the measuring devices. By means of this test board a DC measurement of the 4 test samples was carried out, in order to, on the one hand, determine the general function and, on the other hand, the INL and DNL of the converters. At the AC measurement a Logic Analyser served as measuring device. The input voltage was generated by highly accurate signal generator. As input signal a sine is used. After the start of the measurement the Logic Analyser continuously writes the data into the memory. The sine regained from the data in then transferred into the spectral range by FFT. From that SNR and ENOB can then be determined.

In figure 4 and 5 the measuring results of the DC and AC measurements are shown. The complete function of the flash-ADC could that way be proved.

Outlook

The function of a new flash-converter principle could be succesfully demonstrated. This took, on the one hand, place by the simulation as also in measurements. As a next step the flash ADC will be integrated into other technologies

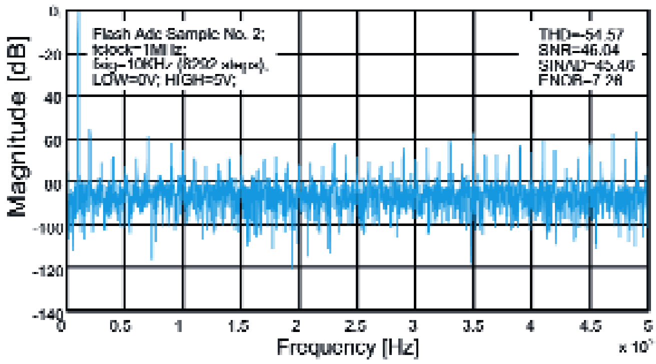

Fig. 5: FFT-spectrum of the flash ADC

with smaller structural dimensions. Here it must be tested, whether the sampling frequency of the current circuit design may be increased any further. Here the objective is 20 Msmaple per second.

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Industrial electronics and measurement engineering

An important milestone in the development of the department in the year of 2003 was the extension of the technological equipment and building up a new measuring technique laboratory in the institute branch Erfurt.
Organized by the donation for innovation, technology and research Thuringia (STIFT), investments could be made within the EU-infrastructure support for the location Erfurt south-east. Owing to that it became a.o. possible, to bring the measuring devices and the technological equipment of the IMMS in the area of microsystem technology onto a high level and build it up in a future-oriented way.
Taking this development into account the department was restructured and will now start its activities as a location overlapping structure in Ilmenau as well as in Erfurt. This is of special importance, as the interdisciplinary cooperation of design and test in the IMMS can be forced and better framework conditions for an even closer cooperation with important research partners of the microelectronics industry in Erfurt south-east could be created. The change of name from "Analyse&Test" into "Industrial Electronics and Measuring engineering" is considered to be more suitable to make up the profile of the department, as the main emphases, on the one hand, include the research and development activities for a great number of sme, in particular from Thuringia. On the other hand, the department carried out a specialization for evaluation, characterization and test of electronic components, assemblies and systems. The department is divided into three factions – smart-power systems, test and RF-systems. With that the successful research and development lines of the last few years are intended to be continued and focussed.

Smart-power systems

The projects in the year of 2003 also included tasks in the area of dimmable adapting equipments for fluorescent lamps and battery management systems for lithium ions batteries (s. p. 49). Work on these two especially emphasized subjects was carried out by the sme. Furthermore, the basic principles for the energy management system for solar applications were provided for with the University of Central Florida (Orlando, USA), which resulted in a patent.

RF-systems

The cooperation with the microelectronics industry started last year in the area of RF-systems was extended and successfully continued. Here, evaluation and test solutions for customer-specific integrated RF-transmitter circuits were in the centre of attention. At the same time test method developments and investigations for an efficient transfer of new integrated RF-circuits into series production took place. Taking the specificity of antennas for the performance of RF-systems into account two final diplomas for the optimization of patch and loop antennas were looked after. Moreover, several projects in the area of RF-PCP design for application specific system solutions of a Thuringian company, as GPS, ISM and GSM-applications were realized.

Test

Within EU and BMBF-research projects (ATHIS*, CAPSENS*, HGDAT*) the evaluation and characterization of circuit structures and integrated circuits in CMOS, BiCMOS and SOI-technologies took place in the year of 2003. In the mixed-signal area main emphasis was put on ADCs and DACs as well as memories with different structures and complexity. For a design-kit the characterization of analog cells in the high-temperature range (–50°C to 210°C (s. p. 43) took place. The optimization of the programming process of fuses started in the past few years was continued with the characterization and lifetest for three other technology variants. Apart from that RF-noise measurements and component characterizations for well-known representatives of the semiconductor industry, as Infineon, Motorola and X-FAB were carried out. The cooperation with the TU Ilmenau was further intensified and resulted in the support of the centre for micro and nanotechnologies (ZMN) at the design of a test field for RF-components. Two final diplomas of students of the TU Ilmenau were looked after by the TU Ilmenau through staff members of the department industrial electronics and measuring technique. Three further students made their practical semester, among them also one lady student from Moscow. Furthermore, a Jordanian lady student made a practical training in the department.
In the coming year the department is planned to be reinforced with personnel, the test of optoelectronic circuits and systems be principally supported and the possibilities of noise measurements in the IMMS be extended by 1/f-noise measurements.

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Analog and mixed signal measurements at SOI-cells

Objective

The main focus of the work carried out up to now was put on the set-up of a measuring set for analog-digital and digital-analog converters. The aim is, to quickly react on inquiries of the semiconductor industry, in which these cells are further developed as well as transferred into new technologies.

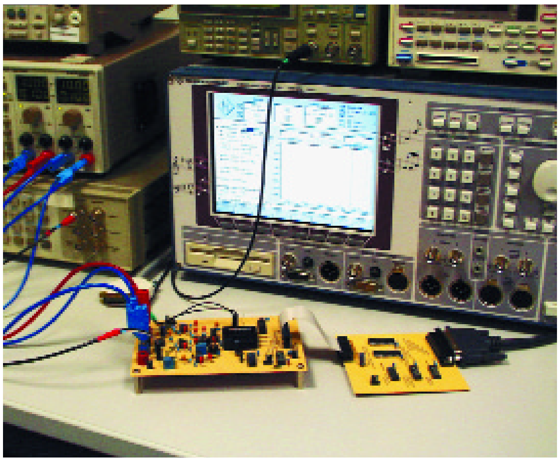

Fig. 1: measuring set for static or dynamic ADC-measurement

The test boards must be set up in such a way that they correspond to the circuits to be tested as well as sufficiently suppress interfering voltages from outside and inside. A useful investment for the solution of these tasks in industrial projects are the experiences gathered up to now from research projects as ATHIS (s. p. 37) and CAPSENS (s. p. 28).
A typical measuring set-up for ADUADCs to 16 bit resolution is shown in fig. 1. It was used for operation under room temperature.
Integrated circuits in SOI-technologies are especially suitable for high temperatures. After finishing the application centre microsystem technology in Erfurt south-east (AZM) a Thermostream TP04300 will, besides other modern measuring technique, be available, by which the SOI-ciruits of –60°C to +225°C can be measured. The conventional test boards are not suitable for this. The discrete components of the measuring circuit as operation amplifier, logics gates a. o. must be kept away from temperatures exceeding 100°C. The traditionally used test sockets fail at temperatures above +170°C.

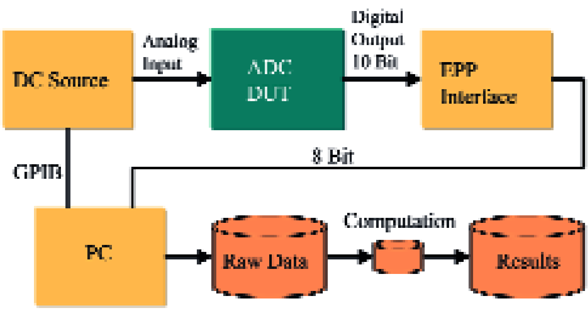

Fig. 2: static ADC measurement

Course and state of research

A simple functional test for an ADUADC is made by recording a transfer-characteristic, from which INL and DNL can be calculated. In fig. 2 a DC-source is controlled by means of a measuring computer. The digital output data are read in and stored via the parallel interface. From the source data INL and DNL can be calculated by means of characterization programs, preferably under Matlab and dependent on the output code be graphically represented. For characterization of the AC parameters the DC-source is replaced by a low-distortion sine generator.
Measuring and characterization programs are available for ADUADCs as well as DAUDACs, by which the characteristics

- Integral non-linearity (INL)
- Differential non-linearity (DNL)
- Total Harmonic Distortion (THD)
- Signal to Noise Ratio (SNR)
- Signal to Noise and Distortion Ratio (SINAD)
- Effective Number Of Bits (ENOB)
- Missing Codes

can be determined.

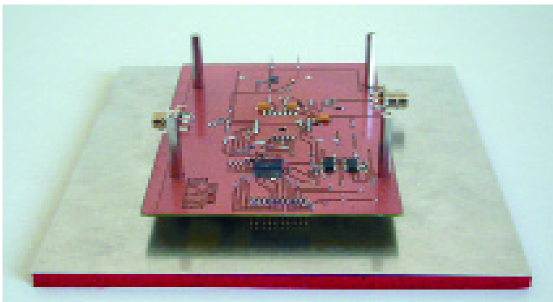

Fig. 3: test board for HAT-applications (view from below)

On behalf of the X-FAB Semiconductor Foundries AG Erfurt operation amplifiers, and comparators and bandgaps were to be characterized besides ADUADCs and DAUDACSs bandgaps. For all cells a measuring and a characterization program was created.
By means of a testboard structure (s. fig. 3) the heat is as much as possible kept away from the components at the bottom side of the prin-

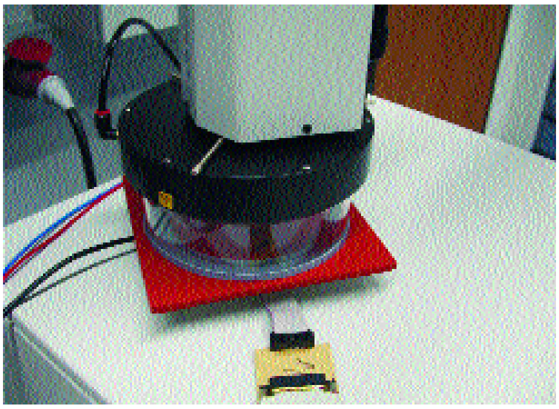

Fig. 4: test board under the Thermostream

ted circuit. The chip to be tested juts out through a slab, which is covered with a heat-resistant silicone sponge. The cap of the thermostream tightly rests on the sponge (s. fig. 4).
Fig. 5 and 6 are examples of measured INL-characteristics of ADC10 and DAC10 at 210°C. Five different bandgap types were characterized in the temperature range of –40°C to +210°C. Fig. 7 shows the DC-characteristics at different temperatures.

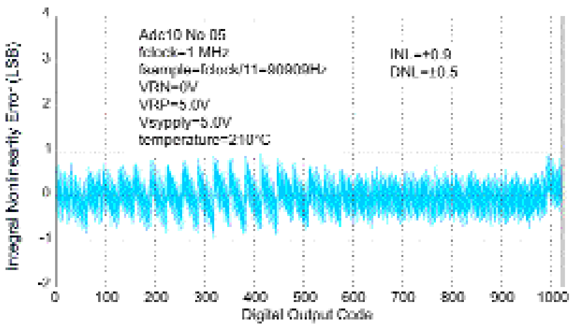

Fig. 5: INL of ADC10 at 210°C

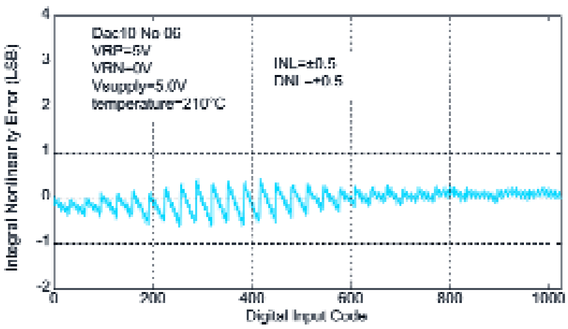

Fig. 6: INL of DAC10 at 210°C

The measuring results were documented in the form of data sheets and are integrated into the kits. A feed-back to the design department is taking place. On this basis the best cells were selected together with the design engineers.

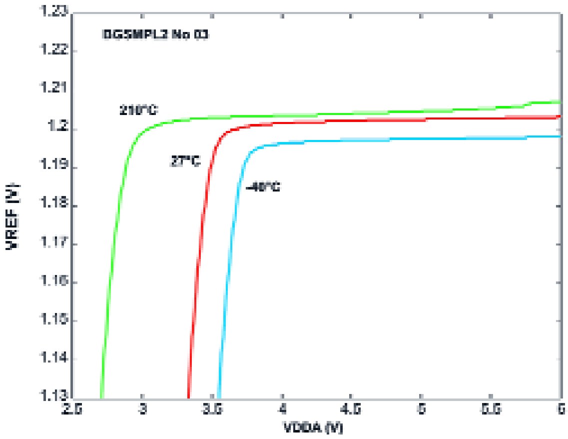

Fig. 7: bandgap characteristics

Outlook

For 2004 the characterization of analog cells for further technologies of the X-Fab AG is on the agenda.

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Evaluation, characterization and testing of RF-ASICs

Objective

Based on the cooperation with Melexis GmbH, Erfurt, the experiences in developing RF ASICs are shown.
The focus is on the special problems of evaluation, characterization and IC test which are described in more detail. Solutions and measurement results are presented for selected examples.

Progress and status of research

Evaluation, characterization, and testing include all work packages beginning with the first package samples and ending with the delivery of specified devices to the customer. It is difficult to separate these three steps of development. There are many relations and feedback between them as can be seen in Fig. 1.
Initially, an explanation of the used keywords is given:

Evaluation	= "Debugging of Silicon"
Characterization	= Description, Datasheet, Specification
Testing	= Quality management, Analysis of failures

Tab. 1: definitions of keywords

Evaluation is the main task when developing ICs. The expected result is a statement whether the IC design was successful or which tasks can be derived for the redesign. But the development is a not straight forward one every time.
Often there are more loops of iterations during the design of highly integrated circuits with a high complexity. The evaluation is done on a small number of devices.
This is completely different during the IC test. Special hardware has to be used which is exactly defined in the test specification running the tester software. Since a large number of devices has to be tested there is a limited time for a single test and device.

Specifics of RF-ASICs

The special conditions for RF-ASICs are due to the circumstance that these ICs are functional only with the appropriate external component. Before using the ICs, these components have to be tuned exactly to the desired application. Special attention has to be paid to the selection of passive components (inductors, capacitors, filters etc.). Only qualified components for the used frequency range can be used to achieve the maximum performance.
The schematic can be dimensioned and optimized on an assembled evaluation board.

Measurement environment

The measuring environment does not consist of hardware only. The software part should not be underestimated. This includes the software controlling the measuring instruments and the software configuring the devices as well.
Most of the ICs include a micro controller and configuration registers. These can be accessed via a specified SPI interface. They are used to adjust the device and compensate tolerances of the production process.

- Hardware:
  - Schematic, external components
  - PCB layout
  - Connecting measuring equipment (adapters, connectors, cables)
  - Switching / multiplexing of measuring instruments
- Software:
  - IC register setup
  - Interface standards
    Compensation of tolerances
  - Adjustments

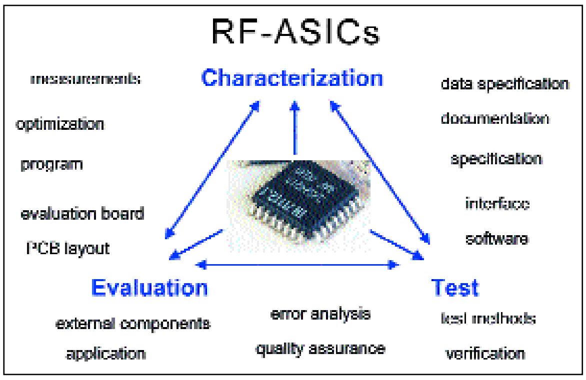

Fig. 1: relations of evaluation, characterization and testing

Test Setup

The following automated test was realized on a HP82000 tester using external measuring instruments like:

- spectrum analyzer
- 2 signal generators with power combiner
- digital oscilloscope
- power supply

A combined evaluation and tester board was designed as a PCB (Fig. 3). The test flow was controlled using Agilent Vee and HPIB interface.
The multiplexing of measuring points was integrated on the tester board. This significantly reduces the amount of connectors and cabling, and reduces the problems with open ends of cables and lines and the need for external coax switches which are much more expensive.

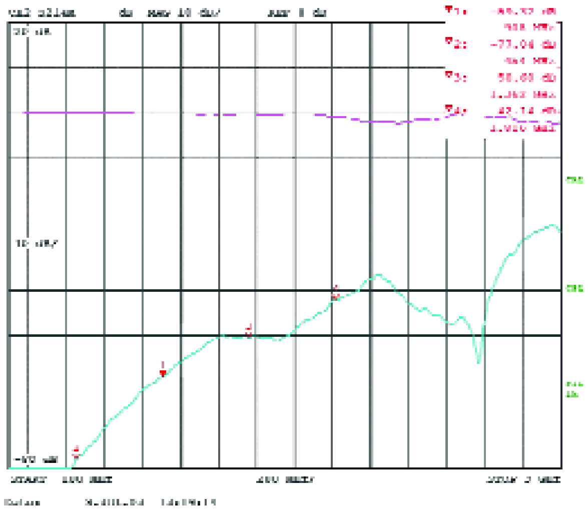

Fig.2: attenuation and isolation of RF-Relay G6Y

The achieved performance of a RF relay is shown in Fig. 2 which is sufficient for most applications. This is subject to the condition that a 50Ohm microstripline environment is used. 3 millions of switching cycles were run to ensure the reliability and repeatability of these contacts. No degradation in performance was observed. Some types of measurements are impossible to be used in automated test setups:

- Measurements requiring loops and iterations (the input signal has to be adjusted depending on the output signal)
- Measurements with complex results on the screen (oscilloscope traces, spectra) which cannot be reduced to a single parameter
- Measurements requiring a lot of time (BER measurements)

This results in the conclusion that a functional test specification can only be developed in close cooperation between designers and test engineers.
The test procedure was continued using a "thermo stream" for measuring the parameters in dependence on the temperature. In order to meet the specification, the characterization had to be done at –40 and +85 degrees. As a result, functional devices could be delivered to the customer as engineering samples.
The experience we gained was very helpful for the redesign and production test setup.

Results

For special RF-ASICs a solution for evaluation and characterization could be established. This is particularly important for small volumes of production.

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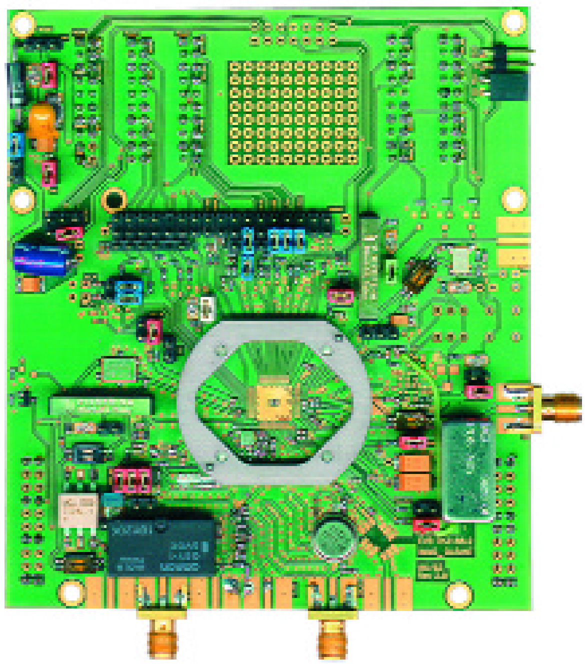

Fig. 3: tester board with fixture for RF-ASIC

Noise measurement at IMMS

Introduction

The noise measurement in electronic circuits is an important area in the parameter characterization of electronic devices.
There is a fundamental difference between RF noise (measurement of F_{min}, Y_{opt}, $G_{ain}/_{ass}$; frequency 0.3 ... 26GHz) and flicker (1/f) noise (determine the parameters AF and KF; frequency 0.1Hz ... 1MHz).
These two tasks require completely different equipment.

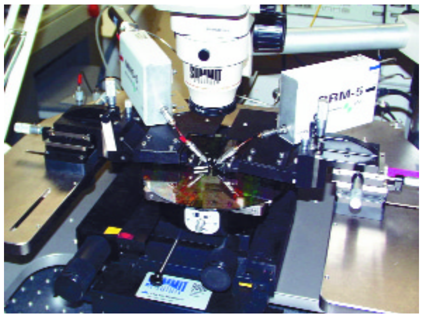

Fig. 2: tuner system with RF probes

RF noise measurement

Designing RF circuits and systems requires accurate models to describe the RF behaviour by scattering parameters and noise parameters. The reason for measuring noise properties of networks is to minimize noise sources in receiving systems.
The noise figure F_{min} of a two-port network is generally a function of the source impedance:
To determine the noise parameters, the source reflection coefficient must be varied by using a tuner on the device input. The NP5 system from ATN Microwave simultaneously and automatically determines the noise and gains parameters.

Fig. 1: RF measurement system

To measure the noise parameters, two different tuners are used in the frequency range from 0.3...6GHz and from 2...26GHz.
It is possible to measure the RF noise on wafer (up to 8”), or packaged at room temperature, since on wafer measurements, we use RF probes with GSG (ground-signal-ground) – configuration with 100 and 150µm pitch.

1/f noise parameter extraction

The flicker noise, also called 1/f noise, is assumed to be caused by surface recombination due to traps and defects in the semiconductor. The output noise spectrum is measured by the dynamic signal analyzer HP 35670A with FFT.

When measuring 1/f noise, the challenge is to be able to measure the noise introduced by the DUT (BJT, MOSFET) without the influence of bias sources, amplifiers or other system components.
The parameter extraction program IC-CAP with the noise modelling tool kit controls the data acquisition via GP-IB control and performs the extraction of the parameters AF and KF.
At IMMS, it is possible to perform a complete noise characterization of electronic devices. The devices (BJT, MOSFETs, MESFETs) can be measured on wafer, packaged, or on boards with a test fixture.

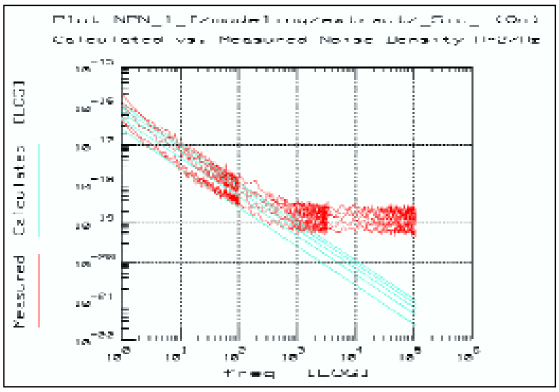

Fig. 3: 1/f-noise measurement on a bipolar transistor (BJT)

Therefore, IMMS is an efficient and powerful partner of the microelectronic industries for these particular measurement tasks.
Within the last years, many orders from microelectronic companies such as Infineon, Motorola, Philips, Melexis, X-FAB, institutes, and universities have been accomplished.

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The new measuring technique laboratory in Erfurt

In September 2003 the activities for building up the measuring technique laboratory could be started. With the new laboratory in the application centre microsystem technique in Erfurt the IMMS and its research partners are opened up new opportunities and improved working conditions. Investigations in a temperature range of –60°C to 225°C can be carried out on-wafer as well as at cased components. The equipment has in particular extended the test possibilities for RF-circuits, for optoelectronics, sensor electronics as well as for technological developments and parameter extraction.
The laboratory contains the following measuring sets:

- Parameter measurement and extraction
- Wafer measurement with PA200 (–60°C ... 200°C)
- Measurement of optoelectronic ICs
- Mixed-signal measurements
- IC-evaluation with Thermostream
- 1/f noise measurement with wafer probe PM8 (0°C ... 150°C)
- RF-measurements
- Soldering and installation place

Although the supply of measuring devices was not finished until the end of 2003, it had already been started from October with the configuration of a few first measuring sets, their installation and the execution of first test operations.
At the mixed-signal measuring set the characterization of analog cells for a design-kit could already been finished. Here, the Thermostream TP04300 could as well be integrated in the test environment.
At the wafer probe PA200 the test suppport for optoelectronic and MEMS-structures was started. First measurements at photo diodes were made. Here, measurements with micromanipulators as well as with probe cards were carried out and active-probes were put into operation. The wafer prober PM8 was used for characterization measurements at test field structures.
With the equipment of the RF-measuring set a test workshop for a customer-specific transmitter IC and measurements in the temperature range of –40°C to 80°C were carried out with the Thermostream TP04300.
The experiences gathered from the first testing tasks are integrated into the organization of efficient laboratory work.

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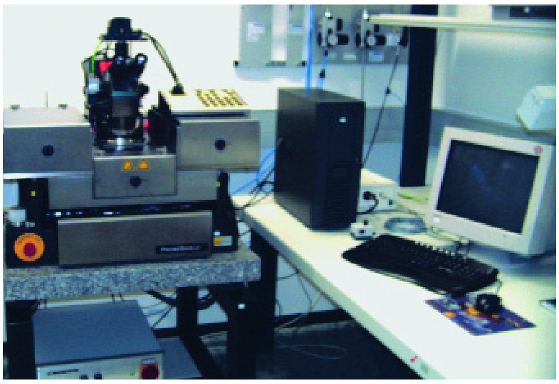

Fig. 1: wafer prober PA200

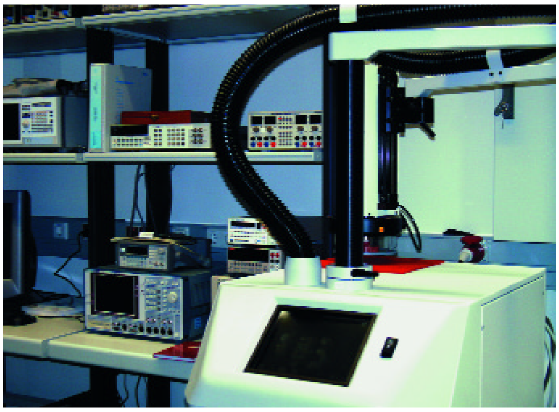

Fig. 2: Mixed-signal measuring set

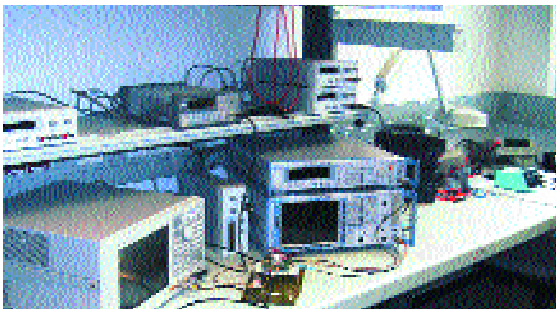

Fig. 3: RF-measuring set

Fig. 4: IC-evaluation system

Measuring system for parameter extraction at gas discharge lamps

Objective

The design of electronic adapting equipments for gas discharge lamps eg. fluorescent lamps, is often made more difficult by the fact that the electric characteristics of the lamps are not completely known. Data sheets of the manufacturers, as far as available at all, are often incomplete and no real help at the circuit design. Some parameters, eg. the striking voltage depend on the static and dynamic operating conditions of the adapting equipment as well as on the environmental conditions (temperature, electric fields) and the ageing condition of the lamp.

Course and state of research

For the solution of this problem a device system was developed, which allows the manual or externally controlled adjustment of the essential operating parameters of an electronic adapting device. With that measuring courses for parameter extraction can be practically organized and comparative investigations of lamps of different manufacturers and different ageing condition can be carried out. The system consists of an ballast-modul for ignition and provision of the discharge current and a separate modul for adjustment of the heating parameters at the electrode filaments (heating modul). Fig. 1 and 2 show the block diagrams of the modules. The modules have the following functions:

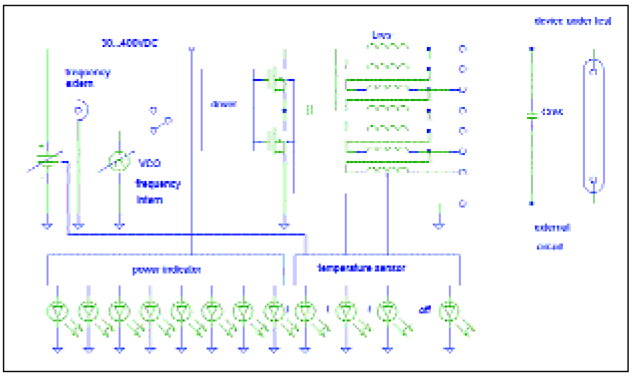

Fig. 1: block circuit of the EVG-module

Ballast-modul

- Adjustable internal DC power supply (30...400V)
- Optionally adjustable internal/external oscillator frequency
- Choke inductor, switchable in steps
- Temperature control and shut down of critical assemblies at overload
- Power indication

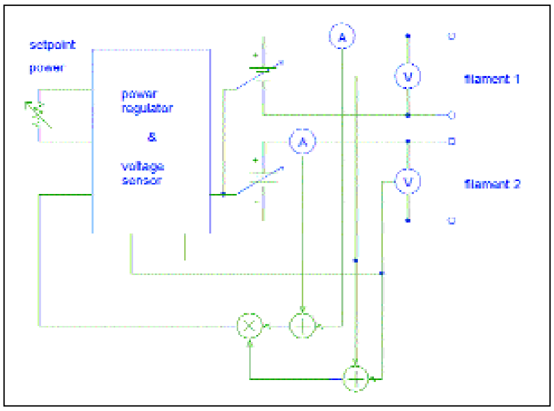

Fig. 2: block circuit of the heating module

Heating modul

- Simultaneous adjustment of the heating capacity for 2 heating filaments (max. 16W in total)
- Voltage control and limitation
- Galvanically insulated outputs with low stray capacitances

By means of the measuring system the striking voltage of a fluorescent lamp (Philips TLD 18W/840) was measured. Through taking the average of five measuring points per parameter setting statistic variabilities were balanced. The measurements were carried out at –30°C and +30°C. Furthermore, the test object was wrapped into aluminium foil for reasons of determination of the influence of the field effect of near metal parts. In fig. 4 the results of the dependence of the ignition voltage on the preheat current of the electrode filaments is shown.

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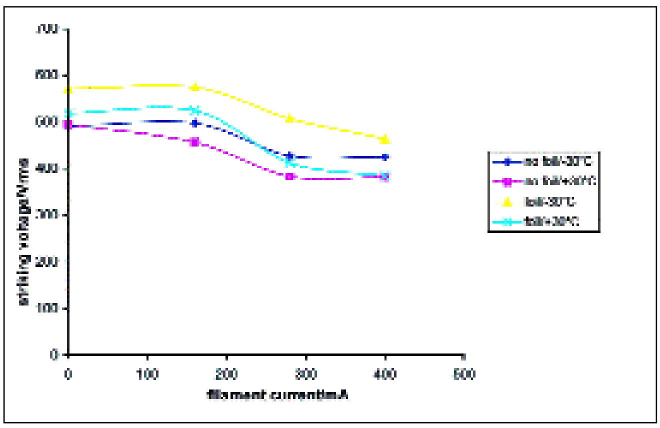

Fig. 3: ignition voltage of a fluorescent lamp of type TLD 18W/840 at two different temperatures and under the influence of strong field interference through the aluminium foil wrapped around.

Memberships in associations, special groups, etc.

- **1394automation e.V.**
- **AMA Fachverband für Sensorik e.V.** - *Fachausschuss „Optische Sensorik“ (technical committee sensor technique)*
- **American Chamber of Commerce**
- **AZT e.V.** - *Automobilzulieferer Thüringen e.V. (subcontractor of the automotive industries)*
- **DFAM** - *Deutsche Forschungsgesellschaft für die Anwendung der Mikroelektronik e.V. (research company for the application of microelectronics)*
- **DFN**
- **EIBA** - *EUROPEAN INSTALLATION BUS ASSOCIATION*
- **EUROPRACTICE**
- **Facharbeitsgruppe Mikrotechnik Thüringen (TMWAI-STIFT)** *(special group microelectronics)*
- **Fraunhofer Gesellschaft / IOF Jena**
- **Leitungsgremium der GI/GMM/ITG-Kooperationsgemeinschaft „Rechnergestützter Schaltungs- und Systementwurf (RSS)“** *(Fachausschuß 3.5 der GI, Fachbereich 8 der GMM, Fachausschuß 5.2 der ITG)*
  (Management body of the GI/GMM/ITG cooperation group “computer-aided circuit and system design (RSS)”. (Special group 3.5 of the GI, special field 8 of TMM, special group 5.2 of ITG)
- **GI/GMM/ITG-Kooperationsgemeinschaft „Rechnergestützter Schaltungs- und Systementwurf (RSS)“** *Fachgruppe 1 „Allgemeine Methodik und Unterstützung von Entwurfsprozessen für Schaltungen und Systeme“; Fachgruppe 2 „Entwurf von analogen Schaltungen“*
  (GI/GMM/ITG cooperation group “computer-aided circuit and system design (RSS)” special group 1 “general methodology and support of design processors for circuits and systems”, special group 2 “design of analog circuits”
- **GMM** - *Beirat (advisory council)*
- **GNT** - *Gesellschaft zur Förderung neuer Technologien Thüringen e.V. (company for the promotion of new technologies)*
- **IEEE** - *Circuit and Systems Society; Electron Devices Society; Solid-State Circuits Society*
- **InnoRegio Südthüringen e.V.**
- **ITG-Arbeitskreis** - *„Zusammenarbeit Industrie und Hochschulen“ (cooperation industry and universities)*
- **ITG Fachgruppe -** *„CAD für den Analogschaltentwurf“ (CAD for the analog circuit design)*
- **Linux LIVE Verband e.V.**
- **Jury des BMWi zum Initiativprogramm „Zukunftstechnologien für kleine und mittlere Unternehmen“** - *ZUTECH 1999 – 31.7.2003 (Jury of the BMWi for initiative program “future technologies for small and medium enterprises”)*
- **Mitglied des „Inneren Arbeitskreises“ FUTUR des BMBF** *(member of the “internal working party of the Ministry of Education and Research”)*
- **MSDN** - *MICROSOFT DEVELOPERS NETWORK*
- **MTT Mikrotechnik Thüringen e.V.**
- **OptoNet e.V. Thüringen**
- **Steuergremium des EDAcentrums**
- **TZM Erfurt** - *Technologie-Zentrum-Mikroelektronik e.V. (technology centre microelectronics)*
- **USB - Implementer Forum**
- **VDE / VDI Fachgesellschaften ITG, EKV und GMM (expert groups)**
- **VDE / VDI** - *Arbeitskreis „Mikrotechnik Thüringen“ (working party microtechnique Thuringia)*
- **VDMA** - *Arbeitskreis „Nutzergruppe Mikrosystemtechnik“ (working party “user group microsystem technology”)*
- **VSIA** - *VITAL SOCKET INTERFACE ALLIANCE*

Papers and Publications

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- Götze M.: **“A Flexible Object-Oriented Software Architecture for Smart Wireless Communication Devices”**
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- Töpfer H.: **„Bit Error Rate Determination of RSFQ Logic Cells by Means of Noise Analysis of Basic Network Components“**
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- Götze M.: **„Entwurf einer Softwarearchitektur für Smart Wireless Communication Devices und darauf basierende Realisierung einer prototypischen Applikation“**
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- Lang Ch.: **„Bi-Decomposition of Function Sets using Multi-Valued Logic“**
  09/2003, dissertation.de, Berlin, 2003, ISBN 3-89825-671-5
- Braczek M.: **„Entwicklung eines systematischen und durchgängigen Entwurfsablauf für die Steuerung mechatronischer Antriebssysteme mit Echzeit-Linux“**
  12/2003, Diplomarbeit

legend:

- **Medea+ –** MEDEA+ is the new industry initiated pan-European program for advanced cooperative research and development in microelectronics
- **ANASTASIA II –** Methods for the automatic design for applications in the mixed-signal area
- **SPEAC –** Specification and algorithms/architecture codesign for highly complex applications of the automotive and communication technique
- **VALSE –** Integrated solutions for the system-on-chip verification
- **ASDESE –** Specific design for ESD and substrate effects
- **ATHIS –** Advanced techniques for high temperature system-on-chip
- **CAPSENS –** Capacitive sensor transducer
- **HGDAT –** Conception and implementation of an evaluation measuring set for RF-ASICs HGDAT
- **IntelliNet –** Networking of intelligent nodes in automation area on the basis of new operating system and bus technologies

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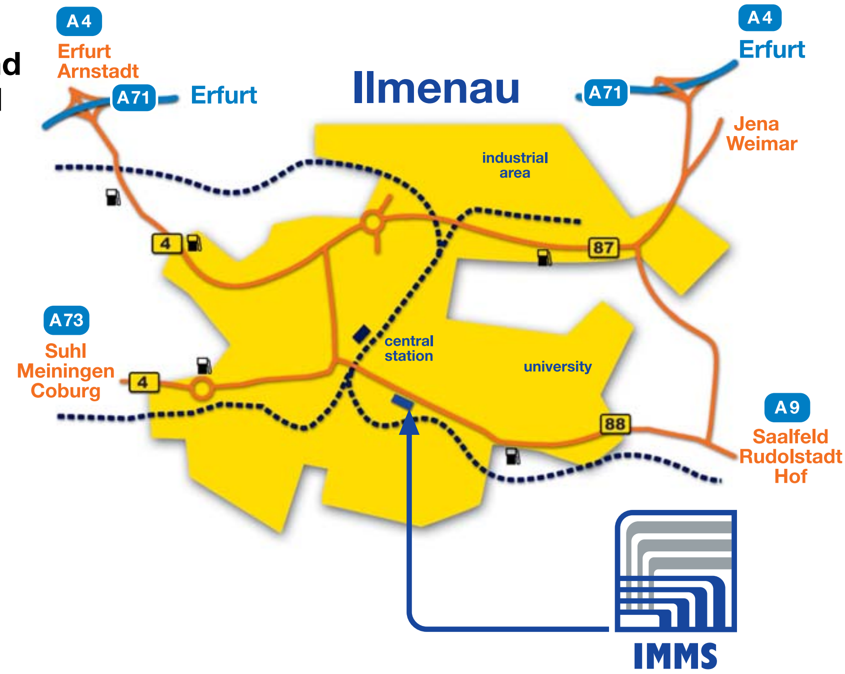

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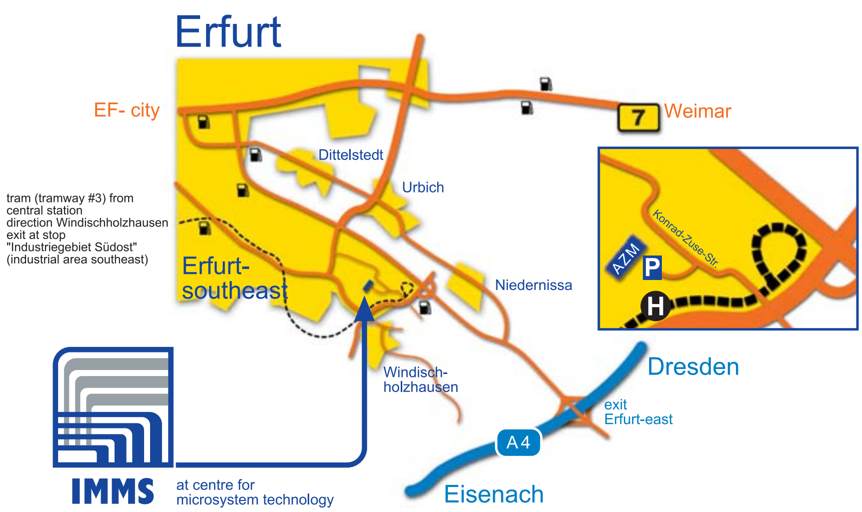

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