innovation
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annual report 2004

Institut für Mikroelektronik- und Mechatronik - Systeme gGmbH

IMMS

You set the goals - we help to carry out them

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Savings on R&D funds endanger the future of the economy as well as the society as a whole.

Source: “For an innovative Germany” (Für ein innovationsstarkes Deutschland, No. 99), BDI, June 2004

Naturally, such a header is provocative in times of tight budgets. However, it’s not all about savings but also about finding ways of increasing future incomes. Therefore, politics as well as companies need to decide, in which tasks to invest the little funds that are still available.

On 19/1/2005, the Thüringer Allgemeine newspaper published the following note: “The Thuringian economy seems attractive. 86 percent of companies make profits or at least make even. Exports have reached new heights. After a long recession the economy is getting stronger again.

The Thuringian economy returns to growth. A recent opinion poll by the Erfurt Chamber of Industry and Commerce found that 82 percent of the interviewed entrepreneurs assessed their business fortunes as positive.”

The main reasons for this trend are the entry into new markets, an international presence and, of course, the world-class quality of the products made by the Thuringian industry. The basis for this success are the research and development, which is on a high technological standard, as well as new methods of cooperation and the management of complex development processes.

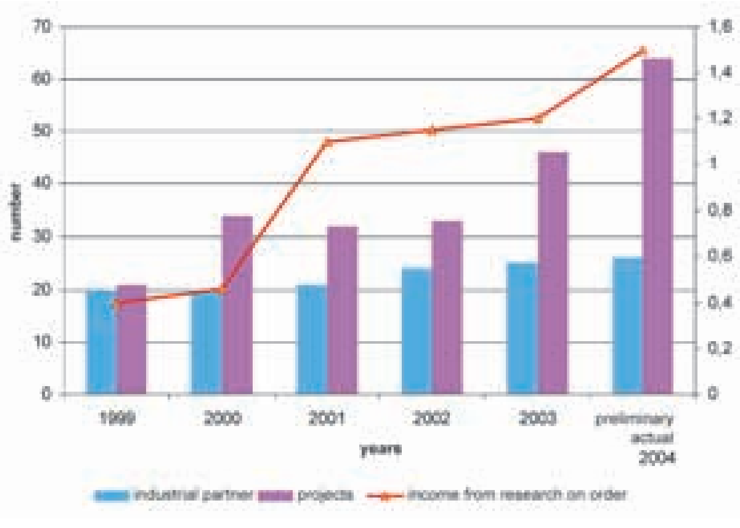

fig. 1: Income from research on order

In 2004, the Institute for Microelectronics and Mechatronics Systems gGmbH was able to continuously and successfully expand its R&D competences. A contributing factor is the move of IMMS gGmbH to new premises on the campus of Ilmenau Technical University (TU) in the Ernst-Abbe Centre for Research and Transfer. This led to a significant improvement of working conditions, which again prompted an expansion especially for the research into nanopositioning machines but also into high-frequency electronic systems. In combination with its other research facilities at its Erfurt site, the institute is now able to provide a broad range of state-of-the-art multi-disciplinary research and development of new technologies and methods. This is based on the cooperation of the institute’s departments of mechatronics, electronics and especially microelectronics as well as microsystem technology.

In all areas of our work, once again the multidisciplinary aspect of the integration of scientists with special knowledge has proven successful. The involvement of specialists from microelectronics, mechatronics, information technology as well as solid-state electronics for the development of complex technical systems has been ideal. In this context the existing departments, which are

- system design
- circuit technology / microelectronics
- mechatronics and
- industrial electronics and metrology,

have focused on their respective tasks and have implemented strategic research programmes. This has fulfilled an important industry requirement. This can be seen from the positive development of the income generated from research for industry (see figure 1).

It is becoming ever more clear that success in innovative and market-leading products demands time, stability and reliability, funds and never-ending motivation. Therefore, the institute will continue to focus its efforts on creating stable long-term partnerships with innovative companies from the microelectronics and mechatronics industries.

We continue to expect politics to create the necessary conditions for R&D – not just in good times but also in difficult ones. Our experience has shown that it is only through joint research projects that many small and medium-sized companies can afford their own R&D. It is also a means for securing jobs for the future. IMMS actively promotes the design of regional clusters of overlapping industries in the respective technology fields. The aim is to bring technological competences together, to develop joint market strategies and to create new business models.

IMMS gGmbH is a partner of the most important of the Thuringian and national innovation networks and of the industrial clusters in the areas of automotive technology, microtechnology, microelectronics and optics.

fig. 2: Ilmenau campus of the Ernst-Abbe Centre for Research and Transfer of the Technical University

The development of technological competences is closely linked with the subjects offered by Ilmenau Technical University. As early as 1996, IMMS was granted the status of an AN institute by Ilmenau Technical University. Currently, we work in intensive cooperation with 12 subject areas of research and teaching and enjoy the possibilities of the joint usage of the scientific infrastructure. Numerous students have participated in IMMS R&D projects. Often they begin their work as student assistants followed by practical training and various kinds of dissertations.
The scientific employees of our institute hold seminars and practical trainings and give lectures at the university's faculties. This cooperation, which is advantageous for both sides, will be continued and continuously expanded.
This report contains an overview of the essential core competences of our institute in the four departments (TBs).
Our strength is our ability to multi-disciplinary operation, which proves itself through our highly qualified scientists in the disciplines of designing microelectronic and optoelectronic as well as complex mechatronic systems. The competence and creativity of our scientific employees becomes an increasingly important part of the development of future strategies by our partners in industry. Cooperation begins not just through applicable R&D but starts as early as the process of the innovation planning - this means the finding of new ideas and products and the assessment of their feasibility under consideration of the latest technologies and design procedures. With this claim we optimistically approach the tasks that will await us in 2005. The institute's management would like to acknowledge all employees for their enthusiasm and motivation. We also wish to thank all of our partners from industry, science and politics as well as the members of the board and the scientific committee for their successful cooperation.

Hans-Joachim Kelm
Commercial manager

Prof. Dr. Gerd Scarbata
Scientific manager

Networking strategy

Apart from the concentration on market-orientated competence areas, IMMS gGmbH has another strategic marketing objective – the active contribution to the design of regional clusters of overlapping industries in various technology fields.
The different technological knowledge, the dramatic increase in the complexity of research and development as well as the increasing division of labour from manufacturing to marketing demand a new way of cooperation from all parties involved.
Companies and all relevant facilities in the region would participate in creating the technological infrastructure. These include universities, research institutes, other technology centres and entrepreneurial centres, educational facilities as well as technology-oriented administrators and associations, etc.
Clusters represent an innovative way of cooperation between economy and science and aim at the cooperative networking of all the important players for innovations. The building of regional clusters enables multiplication and synergy effects whose impacts and sustainability promote the founding of new companies and secure the future of existing ones.
The “networking strategy“ is an important step for the institute towards creating the conditions for the development of new markets but also to get innovative companies interested in the institute’s own location and/or link them to it.

The following selection provides an overview of the various activities of IMMS gGmbH:

edacentrum e.V.
The putting together of R&D competences at German research facilities in the field of Electronic Design Automation (EDA)

German/Dutch network for the generation of standards for industrial communication via Firewire

Live - Linux Verband
German industry association of companies that are active in the field of free software and Linux

Interactive information centre for universities and companies in Thuringia

Network for the economy, science as well as consulting companies and service providers from the semiconductor industry

Automotive supplier association in Thuringia. Research for the automotive industry that is carried out by Thuringian facilities.

Network for optical technologies, departments for optoelectronics and image processing

Fachverband für Sensorik e.V., ama science committee, an expert committee for microsystem technology and optical sensor

Association of education providers and education users of various types, conferences on future developments and invention activities

Regional competence network for quality assurance via image processing systems (VisQuaNet)

Network for connecting traditional competences in the fields of construction, microsystem technology and devices technology

Telematik-Cluster Middle Germany
Network of companies in the intersecting areas of telecommunication, information technology and traffic

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Mechatronics

Objectives

The Mechatronics Department focuses on the following subjects:

- precision direct-drive systems
- analytical tools and equipment
- complex mechatronics systems.

Our ork is characterised by the implementation of an existing idea into a prototype. Conceptual design, modelling and simulation as well as optimisation of parts and devices according to given criteria are part of our tasks.

These are supported by a wide range of software tools (Inventor, MDT, ProE, Ansys, Maxwell, Femlab, Matlab / Simulink; dSpace, etc.) and a solid base of measuring equipment and infrastructure.

The development of complex mechatronics systems requires a close and iterative cooperation of technical designers, simulation experts and control engineers according to the latest scientific knowledge and methods as well as the use of effective tools. Also, constantly accelerating development cycles and an increasing complexity of systems make precise modelling and simulation of the static and dynamic behaviour of systems inevitable for a wide range of applications. As early as the development phase, our processes allow an optimisation of behaviour and represent efficient means for judging the feasibility and optimum utilization of new technologies.

The heterogeneity of complex systems often requires splitting tasks into domain-specific subsystems. This reduces the complexity and allows the use of special simulation tools like network analysers for electronics simulation and MATLAB/Simulink as a mathematical simulation tool or FEM programs for the simulation of static and dynamic deformations as well as the electromagnetic and thermal behaviour of the systems.

For the most exact description of the total system behaviour the results of the detailed simulations are integrated into the overall model in a suitable format. In order to verify the quality of the simulation results, a comparison between the models is drawn by means of measurement data from real systems or experiments.

Not least for the design of optimum controls, e.g. for movement systems, it is essential to have exact knowledge of the system behaviour. Such a controller design is beneficially created by means of rapid prototyping systems (e.g. dSpace), which allow an efficient and quick procedure, not least due to the connection to MATLAB/Simulink. The essential goals of the complex simulation are to minimize the design cycles and to shorten the development phases.

Focus of activity and areas of application

We have developed/are currently developing and investigating the following projects:

- Development of a measuring gauge to Investigate the flow properties of liquids (RheoFilm) (see page 8)
- Design and modelling of drive systems for microtechnologies (MODAN) (see page 9)
- Microstructuring - modular manufacturing equipment for laser micromachining of micro tools and medical instruments (see page 10)
- InnoSKo - innovative controller and construction concepts for multi-axis motion systems (see page 11)
- Identification of drive systems (see page 13)
- 2D movement in multidimensional axes (see page 15)
- SFB 622 - development and investigation of mechatronics precision drives (see page 16)
- Simulation of a controller structure of a planar hybrid step motor (see page 18)

We have planned the following tasks:

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

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RheoFilm - Development of a measuring gauge for the investigation of the flow properties of liquids

EU, G6ST-CT-2002-50165

Objective

IMMS was participating in a European R&D project that also included two German companies as well as both a company and a research centre each from Belgium, Spain and Switzerland. IMMS has taken on the task of developing and testing a measuring system for micro-rheological features of films - a so-called rheometer.
The measurements investigate 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 the fluids that can be used for calibration. Therefore, the development task contains a device concept including measurement and control algorithms and software.
An essential requirement is that all measuring equipment, data recording and analysis programs must be capable of online connection and functionality so that their performance can be demonstrated in an online group test session, a so-called „ring test“ (round-robin test).

Status of the research

The project started with the definition of the demands of the rheometer. The different requirements of the project partners were taken into specification sheet - these were based on the conditions for laboratory set-ups and their fields of application.
The detailed project definition was a reflection of up-to-date research results from basic research projects (R&D partners) and/or customer specifications, which were defined by the industrial partners. They included for example the lubricants (their viscosity, composition, etc.) that were to be examined by the rheometer, the design of the samples and counter bodies (material, surface characteristics, etc.) and the experimental conditions (temperature, humidity, air pressure, mixture of ambient gases, duration of test, etc.).
On the basis of these requirements a first prototype of the rheometer was developed (see figure 1). This prototype was used to verify the implementation of the measuring and calibration procedures. However, due to its specifications the prototype requires sophisticated laboratory equipment like the availability of compressed air. Therefore, a second prototype was developed (see figure 2). This second prototype was used to realize the online ring test in spring 2004.
The online ring test was implemented on four identical rheometer prototypes, which were located at the sites of the different research partners, and the same experiments were carried out simultaneously. Both the controlling of all measuring instruments and the transmission of the measured data and/or the evaluated data took place from Ilmenau.
After the successful online ring test the existing prototypes were available to the project partners for further investigations. The experiences, which the partners are continuing to have with the measuring instruments, will be integrated into the advancement of the measuring and evaluation procedures and the instrument technology.

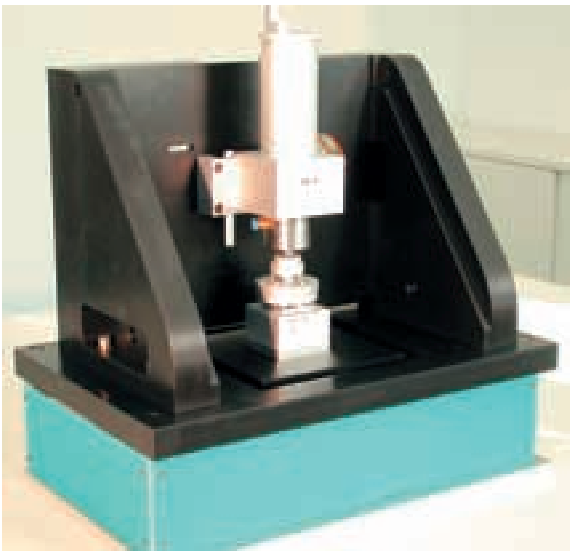

fig. 1: First rheometer prototype

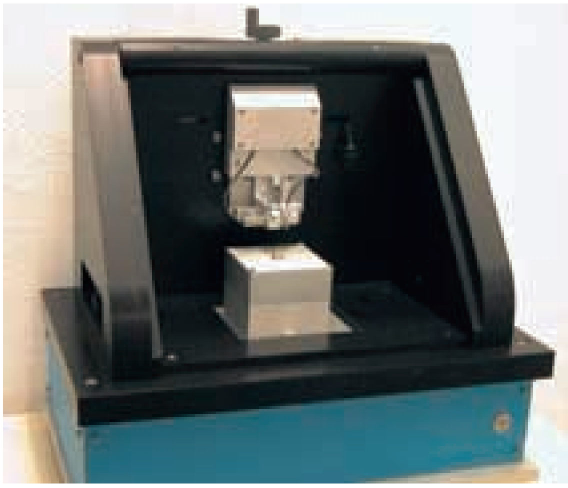

fig. 2: Second rheometer prototype

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MODAN - Design and modelling of drive systems for microtechnology

BMBF, 169V1554

Objective

As part of the R&D project funded by the BMBF (German Federal Ministry of Education) IMMS is involved on two fronts. The first point of focus is on the evaluation of simulation tools that are intended to support engineering design in the field of mechatronic drive systems. From these investigations specifications are to be derived that will assist further developments of the design methodology with particular relevance for the simulation software “SimulationX” and “SESAM”.
The second point of focus for IMMS is the development of a variety of mechatronic drives that are based on the modular principle, for example electro-dynamic direct drives and mini and micro drives such as actuators relying on electro-magnetic resonance principles. Further investigations examine the use of precision drive systems (mentioned above) in multi-axis machines under real operating conditions.

Status of the research

From the beginning of the project, several work teams have been evaluating the simulation tools in relation to selected drives. At the same time, various drive systems have been developed. Many preliminary investigations were carried out with several experimental setups. They 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 LMS 20.
Up to this point, the modelling of the planar direct drive took place with coupled partial models for electro-magnetism, mechanical structure and control algorithms. The electro-magnetic behaviour and mechanical behaviour were simulated with FEM. The modelling of the controls was realized with Mathlab/Simulink. The disadvantages of this kind of modelling are longer calculation periods for the FEM simulation and the indirect data link of the partial models.

fig. 1: Electro-dynamic planar motion system PMS 100-3 for use in analysis equipment

The latter is not able to, or if it is, it only does with great difficulty, allow the implementation of all phenomena for the models, for example the influence of temperature modifications on the system reactions. The aim of these project aspects is to bypass the described disadvantages of the linked partial models with the help of a simulation of the whole system by using network elements. The model of the network will be developed in three steps. In the first step, which has already been realised, the magnetic behaviour is represented by a network.

Outlook

The current work focuses on the extension of the model by mechanical elements. After that, in the final project phase, the components of the control algorithms will be included into the model. And then finally, in addition the developments of the drive systems will be finished.

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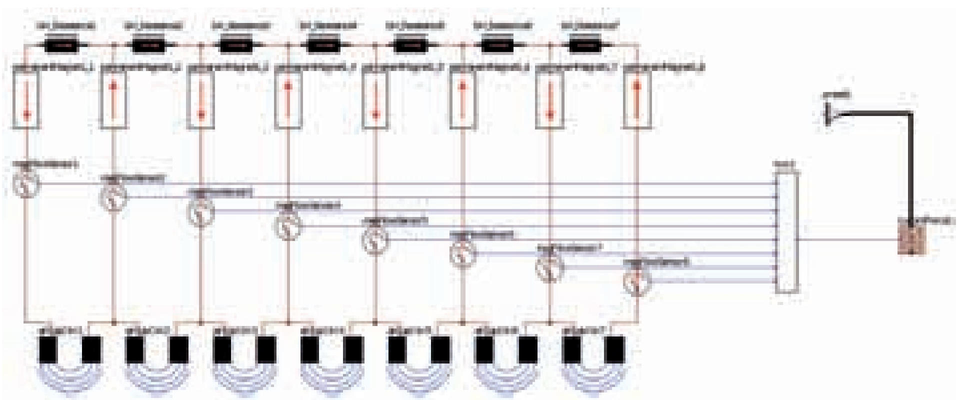

fig. 2: Model of a magnetic circuit of a drive chain with network elements in ITI Simulation X

Microstructuring - Modular manufacturing equipment for laser-micromachining of micro tools and medical instruments

BMBF, 03i2912C

Objective

As part of the integrated research project, which is promoted by the BMBF within the framework of the InnoRegio initiative, the technology of laser-micromachining will be improved. The basis for this development will be the results of the project „Innovative Control and Design Concepts for Multi-Axis Drive Systems“, which was successfully completed in 2004.

A point of focus for the development is a new modular machine concept for 3D machining systems including integration options for different laser sources.

Areas of application of these laser micromachining processing plants are the production of medical instruments, e.g. stents, and of micro tools, e.g. cantilevers, which are used in atomic force microscopes (AFM) and in devices for micro and nano-measuring technologies.

The high requirements of the modular laser micromachining processing unit machine regarding the speed of the laser processing and the accuracy of the 3D manufacturing curve depend on a) the requirements of the end users of the laser processing unit machines, which require high throughputs for an economical operation, and b) on the requirements of the users of the products that have been manufactured with the laser system, who have high demands concerning accuracy and surface quality.

The machine concept is based on the electrodynamic planar drive of IMMS, which is to be extended by one to three further drive axes, e.g. for the z-feed of the portal-mounted laser head or an axis for rotating the work piece. This shall facilitate the three-dimensional processing of objects.

A new control concept is also being realized – it shall enable a synchronized movement of the different drive axes and of the laser.

Status of the research

Since the beginning of the project extensive preliminary investigations, e.g. for the design of the coils cooling system for the PMS 200 and for the increase of the positioning accuracy by the correction of measurement system errors, have been accomplished. The first prototypes were developed on the basis of the machine concept, that was jointly developed with the other project partners (see figure 1). The machine has four axes and can be equipped with a portal-mounted z-axis and one rotary axis that is mounted on top of the planar stage or on the z-axis, in addition to the PMS 200.

The design was supported by the simulation of critical components, e.g. with the help of FEM. The simulations analyzed static and dynamic parameters and especially the reactions of the machine to thermal influences, for example by the energy contributions of the drives.

Outlook

In early 2005 the assembly and initial start-up of the first demonstration system of the laser-micromachining system will take place. When the tests have been successfully completed, this machine will be used for the further devel-opment of the control systems.

At the same time, the development of the second demonstration system, which is intended for examinations concerning the possible replacement of the laser sources, will begin. The demonstration systems No. three and four will be used to develop specifically adapted laser sources and special laser manufacturing processes.

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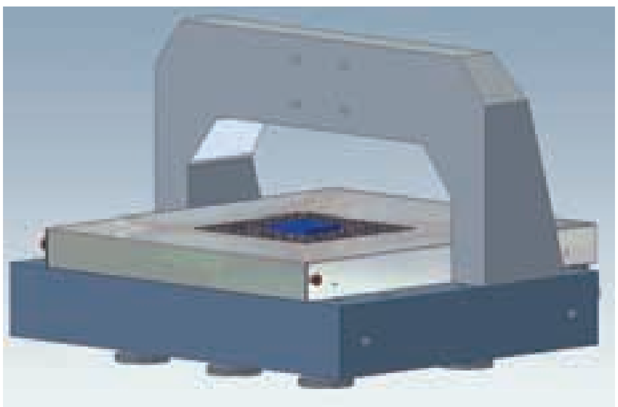

fig. 1: CAD model of the first demonstration unit of a laser micromachining system

InnoSKo - Innovative controller and construction concepts for multi-axis motion systems

BMBF, 0312904A

Objective

High-precision motion systems have a wide range of applications, among others laser precision-machining uses such motion systems for work piece positioning.
Modern laser precision-machining systems require improved performance parameters like position accuracy and motion speed as well as improved functional parameters like a large number of motion axes. For example, the precision-machining of stents requires apart from the planar x-y-axes a further rotary axis for stent positioning and a z-axis for the positioning of the laser.
The development of concepts for such multi-axis systems and their validation by laboratory prototypes were the focus of a joint project, which started in 2002 and finished this year.
The joint project with our industrial partners in the region, i.e. LAT Suhl AG, LLT Applikation GmbH and TETRA GmbH was supported by the German Federal Ministry of Education and Research (BMBF) within the framework of the InnoRegio support programme.

fig. 1: 4D system with laser

Status of the research

The project's main points of focus were quite diverse and ranged from the simulation and optimization of motion system components, via the finite element method, to the development of controller algorithms with regard to enhanced performance and reduced costs. The developed controller algorithms were to be validated by a laboratory prototype of a 4D motion system for laser precision-machining. Laser precision-machining with the realized prototype was able to achieve accuracies of ± 5µm.

fig. 2: Application example: medical needles

The 4D motion system prototype consists of a planar electrodynamic air-guided direct drive (developed at IMMS) that has been extended by an additional rotary axis as well as a z-axis. The control of the prototype follows the principle of trajectory controlling. The characteristics of this principle are the use of a common coordinate system for all axes, which is attached to the actual position. However, there was one problem to be solved, which resulted from the coupling of all axes – the task was to develop a transformation matrix for axes with different system characteristics.
The controller prototype was designed with the help of simulink and then implemented on a DSP system. But the DSP system has disadvantages with regard to costs and performance updates. DSP cards and processors have longer product cycles compared to conventional PC processors, so a controller that works under Real Time Linux avoids these disadvantages. Therefore, one point of focus for this project was the development of a controller that would work under Linux.
The use of Linux as an operating system allows two operational modes - the usage of the motion system as an OEM or as a stand-alone system. And another advantage is the possible remote maintenance of the system due to the implemented client-server technology.

Outlook

The joint project realised the development and validation of controller concepts for ultra-precision multi-axis motion systems (4D and 5D). Controller parameters like the synchronisation of axes were provided by the application of laser precision-machining. The machining of stents for example requires an optional synchronization of the x-y plane or the x-rot x-plane. These switchable interpolation planes have been implemented in the laboratory prototype. The objective for the next-generation motion systems is the synchronisation of all axes, i.e. up to five axes, depending on the application. These tasks are a focus of the follow-on microstructuring project, which has started this year.

One main point of focus was the development and implementation of a controller that is working under Real Time Linux. A first prototype for a 2D controller has been realized. Future project tasks like the implementation of additional axes and the increase of the trajectory speed by optimising the controller cycles will also be investigated by the microstructuring project.

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Identification of drive systems

Ziele

The control of innovative drive systems like the PMS 200 that has been developed by IMMS uses modern control strategies. These can be implemented as state space controllers with an observer and have a parametric model as their design basis.

The more complete the description of a system or a process, i.e. the more information about it that is available, the easier it is to derive feed forward and feedback control strategies.

One form of system descriptions are parametric system models (state space differential equations), whose parametric elements with regard to quantity are yet to be determined. Another widely used way for the description of linear systems are non-parametric descriptions, for example bode diagrams.

The following examinations focused on the quantitative determination and interpretation of these descriptions on the basis of sampled measuring signal data.

Status of the research

In order to obtain information about system properties these characteristics have to be stimulated. In order to design meaningful stimulation signals a theoretical system analysis and a priori information are required. The IMMS developed a two-stage strategy to identify drive systems. The strategy distinguishes between the stimulation in an open-loop system (stage I) or a closed-loop system (stage II).

Stage I:

At the beginning of the design and optimisation process no controller as yet has been available. For the design of the first controller and observer a simple process model is used, whose parameters are to be determined with regard to quantity.

$$a = -D \cdot v + K_m \cdot i + F_c \cdot sign\,(v)$$

a = dv/dt...acceleration,
v = dy/dt...velocity,
i... current, Km...current-acceleration-factor
Fc...static friction coefficient

The control signal is the current i (input) and the measured variable is the position y (output).

The stimulation of a drive system in an open-loop with weak damping, an integral character and a limited travel range of the plant is difficult. Therefore, the choice of the stimulation signal form as well as the monitoring of the stimulation sequence must be carefully planned. Furthermore, friction parameters are extracted from the sampled data in order to compensate their non-linear influence by a feedforward control (e.g. static friction).

The measuring data must contain a certain information content in order to be able to receive

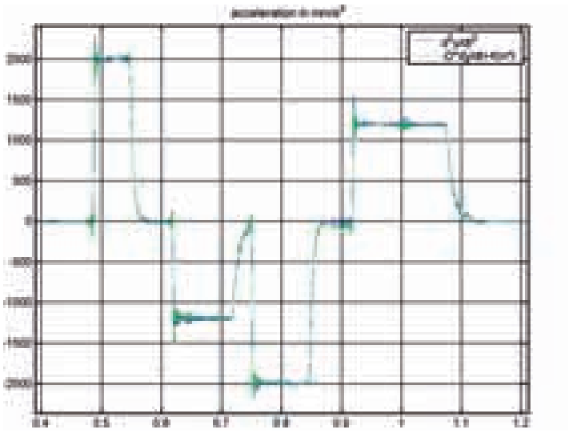

fig. 1: Acceleration, sampled and simulated

unbiased parameter estimates. For example, reliable statements about the current-acceleration relation can only be expected if a pronounced acceleration behaviour can be recognised in the measuring signals. It is the task of the identification algorithm to generate appropriate stimulation signals and to consider significant signal sections for the parameter identification.

After the elimination of systematic disturbances by suitable filters in the measuring signals (e.g. minimising constant disturbing forces by inclined drive), filtered signals are handed on to an estimating algorithm (e.g. LS) for the extraction of the model parameters

Stage II:

After the verification of the estimated results a provisional controller and observer are designed and the loop is closed. The following frequency response analysis is only meaningful if it is guaranteed that the closed loop shows a linear behaviour when stimulated.

The control signal u is overlaid by the stimulation z and the system reaction y is observed. Three time series are sampled (see figure 1). During the time when the signals are traced the reference value w is kept constant.

Investigations have shown that the choice of the stimulation sequence has a crucial influence on the quality of the frequency response measurement.

Two different procedures are used:

- Sequential stimulation by harmonious signals of a constant frequency
  - advantage: • reliable estimated values
  - disadvantage: • low resolution
    • long measurement times
- Stimulation by a special chirp signal
  - advantage: • resolution depends on the measurement time
    • comparatively shor measurement times possible

The sampled signal data u, uz and y are transformed to the frequency domain by FFT. The desired frequency responses are gained by division:

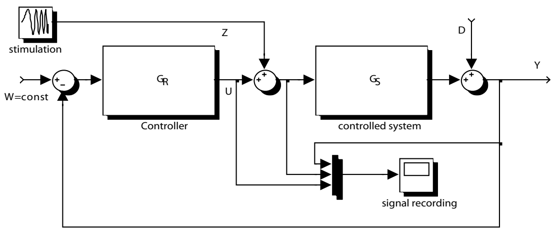

fig. 2: Principle of frequency response measurement

$$G_S = \frac{FFT\{y\}}{FFT\{u_z\}}$$ .... frequency response of the system

$$G_R = -\frac{FFT\{u\}}{FFT\{y\}}$$ .... frequency response of the controller

All other frequency responses in the control loop can be computed from these two frequency responses. As usual, the representation is achieved in the bode diagram.

The verification of the measurements is accomplished with the help of simulations of the parametric system models and the computation of the signal coherence.

Outlook

The developed methodology for the identification of the parameters is transferred to different drive systems. IMMS cooperates with other industry partners to find practical solutions and to support the interpretation of the results.

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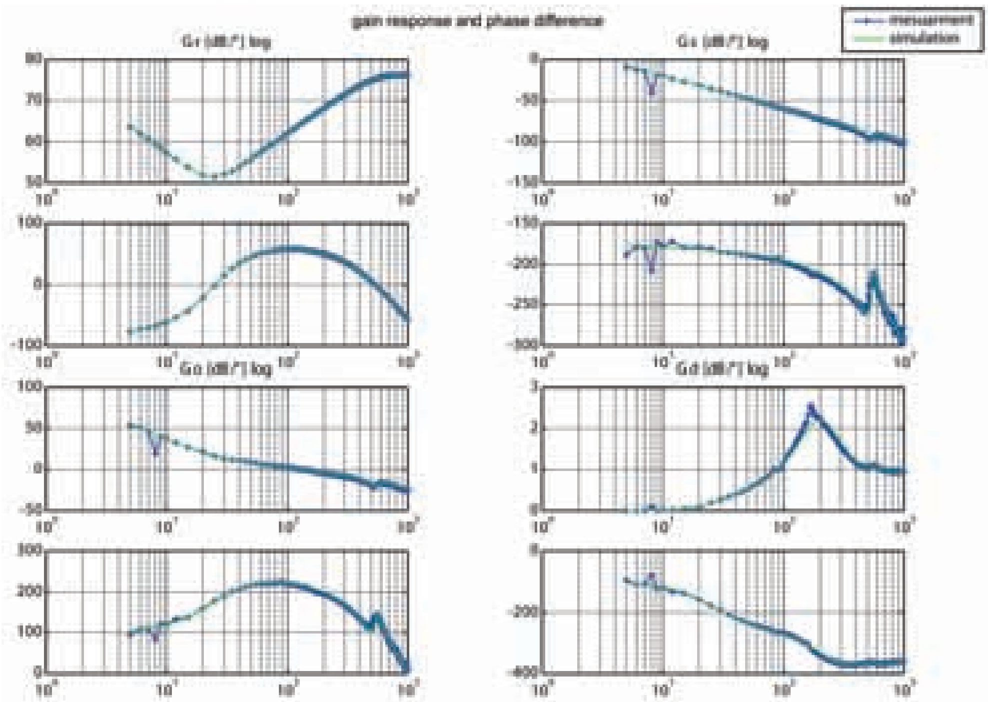

fig. 3: Bode diagram as a result of frequency response measurements

2D movement in multidimensional space

Objective

Apart from their dynamic characteristics, efficient drive systems are also characterized by their ability to realize complex multidimensional motion paths.
At the TU Ilmenau and IMMS a high-grade specialized control algorithm („vector path control“) was developed for the synchronous (interpolated) control of movements in two coordinate directions (e.g. X-Y plane).
The extension of a planar drive by additional movement systems, which enable movements in further coordinate directions (e.g. an A-axis - rotation parallel to the x-axis), and the demand for synchronized movements (path interpola-tion) required an advancement of the control algorithm. This topic was part of the research project „InnoSKo“ (s. page 11) and subject of a diploma thesis that was supervised by IMMS.

Status of the research

Modern machine tools usually combine several different propulsion principles (direct drive or spindle drive with shaft joint, etc.). The traditional method of control is to design specific controllers for each axis. The controllers receive the target value (e.g. reference speed and target position) from a master system.
In contrast to the traditional method, the core of the algorithm for „vector path control“ does not differentiate by real axes, but enables the direct consideration of the required kinematic path values (target position, reference path speed, max acceleration, etc.) by using forward and backward transformations. This becomes possible due to the division of the kinematic values into target direction (z) and path error (e) direction.
Following the existing controller concept and considering the limited resources of the given hardware, the first development stage included the design of an algorithm that was able to select the 2D axis combination (movement plane) freely at run-time. It is for example possible to choose a synchronized movement in the X-Y plane and then to choose a movement in the X-A plane.
At first, the solutions and ideas were examined on the basis of simulations. Then, thanks to a continuous design flow, they were directly implemented and tested for a real demonstrator. The concept for the demonstrator was developed on the basis of the requirements of our project partners from the industry. An existing planar drive system (XY direct drive) was extended by an A-axis (rotary direct drive) and a vertical Z-axis (spindle drive).
The complete drive was successfully integrated into a laser cutting system.

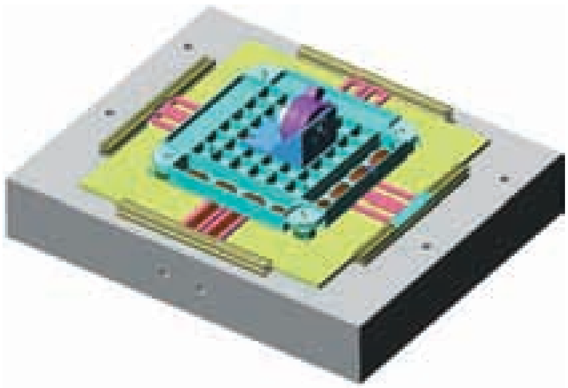

fig. 1: Planar drive with rotary axis

This new functionality hugely extends the processing options. It is now possible for a CNC program to realize paths both on plane surfaces as well as curved surfaces (cylinder envelope) in the lower µm range. By merging a Z-axis it is possible to achieve a correction of the laser focus and thus to improve the cutting quality.
A second development stage focused on the extension of the transformation algorithms. The basic idea of the „vector path control“ was extended to more than two axes. The synchronization of the total movement in (n) coordinate directions is controlled by one target-controller and (n-1) independent path error controllers.
Alternative possibilities were also analysed and examined in a diploma thesis. Initially, due to the different requirements regarding the efficiency of the hardware, the algorithms could only be examined and compared by simulations.

Outlook

Positive simulation results are to be verified by additional real measuring data. After the solution of hardware-specific realization problems, the new algorithms will be implemented for new and existing systems.

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SFB 622 – Design and investigation of mechatronic precision drives

DFG, SFB 622

Objective

IMMS has been participating in the collaborative research centre 622 (SFB 622) “Nanopositioning and nanomeasuring machines”, which is funded by the German Research Association (Deutsche Forschungsgemeinschaft), since 2002. The objective of this research project is the exploration of scientific and technical foundations for the design and realisation of nanopositioning and nanomeasuring machines.
The demand for research on this subject results from the ever-increasing requirements of the accuracy for positioning, measuring and machining of objects within large operating ranges. This applies to the field of future-orientated technologies like semiconductors and e-beam or x-ray lithography. As a subproject within the collaborative research centre, IMMS is concentrating on the development of nanopositioning systems for large movement ranges. The objective of the research activities is the realisation of a positioning system with the following specifications:

- travel range: 200 x 200 x 5 mm^3
- measuring resolution: 0.1 nm
- positioning uncertainty: 3 nm
- positioning speed in x, y: 10 mm/s
- environment: atmosphere, air-conditioning chamber

The following main topics for the research activities can be derived from this objective:

- Investigation of the suitability of aerostatic guide elements for nanopositioning systems
- Development of an overall concept for the intended positioning system
- Layout and optimisation of functional concept details
- Successive realisation of demonstrator prototypes for the validation of theoretical results

Status of the research

The previous activities regarding the investigation of the suitability of aerostatic guide elements were continued with the experimental examination of cylindrical aerostatic linear guides. For such guide elements the compressed air radially enters the circumferential air gap through a porous media layer. The elements are self-centring on the guide axle. With regard to the requirements for accuracy, the remaining noise of the guide elements proves to be a critical parameter. In order to capture precise data with regard to this issue, a laser-interferometric test set-up with a measuring resolution of 0.1 nm was realised. The experiments demonstrated that the aerostatic guide elements show very little noise with amplitudes of less than 1 nm over the whole operating range. Figure 1 shows a measured characteristic timeline as an example. These results proved the suitability of aerostatic guide elements made of porous media for use in nanopositioning.

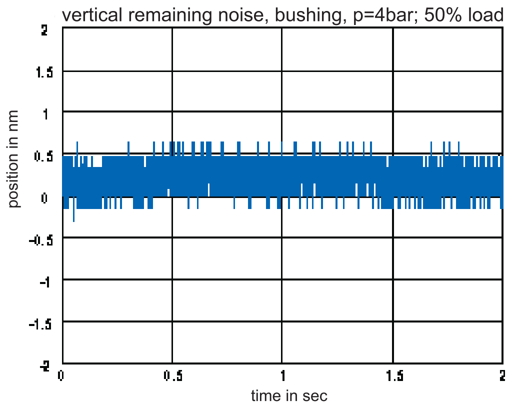

fig. 1: Remaining noise of cylindrical aerostatic guide elements

Future activities in this field will concentrate on the examination of the elements’ behaviour in pre-stressed configurations as well as the investigation of the energy entry into the system due to the airflow.
A second focus of the research work is the concept development, dimensioning and initial assembly of a demonstrator prototype for a linear movement of 200 mm on the basis of the development of an overall concept for a 200 x 200 mm^2 planar positioning system.
This positioning system has a linear electrodynamic direct drive with moving permanent magnet circuits. The slider is aerostatically guided using cylindrical bushings.

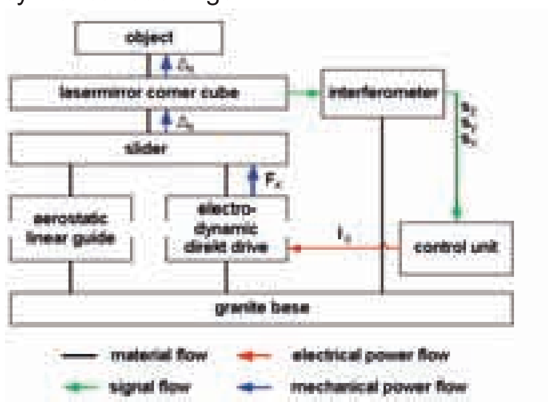

fig. 2: Functional scheme of the demonstrator prototype

A corner mirror cube made of Zerodur© that is mounted on the slider provides a thermally stable reflector for the laser-interferometric measurement of the x, y and z-position of the slider. Figure 2 shows the functional structure of the prototype.

Apart from the design of the couplings, special attention was paid to the thermal behaviour and it was for this reason that the option of cooling the drive coils was provided.
For future research tasks the demonstrator prototype will enable tests of the drive as a complete system and especially the detailed examination of the thermal and dynamic characteristics. At the same time, due to the modular design, a practical test of concept details, for example of special couplings within the complete system, will be possible.
A third work package were the experimental examinations concerning the achievable accuracy for integrated multi-axis drives that had been carried out with the PMS 100-3. In order to achieve this task the planar motor in its triangular configuration was additionally equipped with a laser-interferometric measuring system with a resolution of 1 nm (figure 3).
This configuration enabled successful tests to

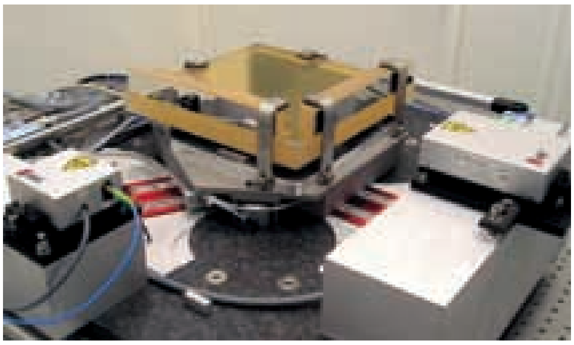

fig. 3: PMS100-3 with laser-interferometric

implement the laser measuring system without a mechanical blockage of the slider rotation. As a result of detailed examinations of the system's operating performance a number of approaches for its increasing its accuracy as well as valuable information for future developments was derived. In principle, the experiments showed that the combination of integrated multi-axis direct drives and laser-interferometer measuring systems is a reasonable and promising approach for the design of nanopositioning systems for large movement ranges.

Outlook

The main focus for 2005 for the continuation of the described activities will be the examination and advancement of the demonstrator prototype. This includes the following tasks: identification of accuracy-limiting factors, derivation of design rules and guidelines for the optimisation of the direct drives and new findings concerning the design of couplings and the thermal characteristics of such positioning systems. At the same time a comprehensive model for direct drive nanopositioning systems, which includes internal transmission characteristics, is to be created. This model allows the assessment of the system performance, especially with regard to dynamics and accuracy, in the early design stages.
The advancement of the demonstrator into a two-dimensional positioning system will be another major step to achieve the SFB 622 objectives.

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HOPS - Simulation of a controller structure of a planar hybrid step motor

TMWFK, B 609-01040

Objective

Mechanical engineering applications worldwide demand ever-increasing speeds and levels of accuracy. For drives and actuators a trend towards the use of direct drives can be observed because these drives avoid the disadvantages of conventional rotary spindle drives, such as clearance and resilience. The elimination of gear units reduces the size and weight and improves the dynamics of direct drives. In order to use the full potential of direct drives regarding precision and speed, it is not sufficient simply to operate linear step motors in an open-loop control system, but a closed-loop control of these drives becomes necessary.

As part of a joint project that is funded by the TMWFK (Thuringian Ministry for Science, Research and Culture), modern non-linear algorithms for the control of step motor drives are being developed. The objective 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 for all speeds. In order to meet these demands, particular models of the dynamics involved as well as ideas and algorithms for suitable and effective control systems are required. The main focus for IMMS is the development of multi-axis state control systems for path control. This also includes the examination of the suitability of multi-axis controllers that are available on the market.

Status of the research

The so-called SPiiPlus that is made by a company called ACS Tech80 (USA/Israel) has turned out to be an economical solution for future industrial use. To this end its controller structure was copied and examined by means of Matlab/Simulink. The scheme for one axis is shown in figure 1.

In order to obtain a first approximation for the parameters (controller and filter adjustment), a linear motor model (double integrator with damping) was simulated for one axis. The corresponding motor characteristics like the conversion factor between controller current and acceleration, etc. have been determined experimentally at the planar step motor. These parameters were used by the motor model.

The determination of the optimum controller adjustments was carried out with the help of frequency response analyses of the simulation calculations. Additionally, the transient response for fast positioning events and the controller behaviour for the measurement signal noise were considered for the determination of the parameters.

Subsequently the model was extended to the three-axis model (x, y and the rotation in the motion plane) of a planar step motor. Then the motor model was replaced by a real planar step motor belonging to a project partner. A dSPACE DS1103 was used for the control hardware. Unlike the 20kHz sample frequency of the SpiiPlus, it was impossible to realise the controller software on the dSPACE system with more than 10kHz. According to our current knowledge, this leads to a decrease in performance.

The fine adjustment of the parameters (compensation between model and real motor) was carried out by means of frequency response measurements. An additional interaction between the two single-axis controllers of the planar motor was also required. These controllers are responsible for the assignment of currents for the y_1 and y_2 movements, which are equivalent to the currents for the y-movement and the rotation, so that they correspond to the real geometric arrangement of the motor elements.

The default configuration of the controller software did not provide for this cross connection between two axes, which meant that the firmware had to be modified. Furthermore, the standard configuration only provided for a sine and cosine commutation. Experimental examinations showed that the characteristics of the controller concerning constant speed and stiffness improved when specific harmonic waves were inserted into the commutation function. This led again to a change of the firmware.

The quality of the position measurement signals proved to be another influencing factor for the stability of the controller. The motor used for these experiments has an internal Hall-sensor measuring system. The signals are subject to a hysteresis due to their magnetic characteristics. They also show quite a high noise ratio. However, this can only be eliminated in parts by filters because the phase shift that arises from the filter has a negative effect on the controller stability.

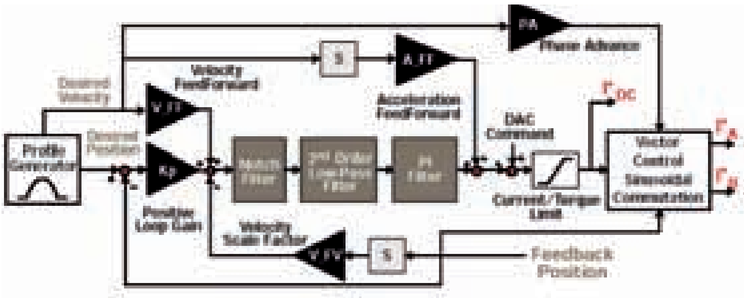

fig. 1: Controller structure for a SpiiPlus axis

Outlook

The main focus of future tasks will be on the verification of the simulation results for the modified firmware of the SPiiPlus. Furthermore, the characteristics of the measurement system will be improved.

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System Design

In 2004, the activities of the “System Design“ department continued to be focussed on the design and realisation of complex embedded systems. Such a system always has to be considered as a unity of both hardware and software as well as of communication components. The department is subdivided accordingly into three divisions, in which the aforementioned topics are pursued and actively developed.
The main activities of the division “Digital signal processing / programmable hardware“ are centred around hardware design methodology (model-based design), hardware modelling, and hardware realisation on various target platforms. They can include for example ASIC, FPGA or complete PCB designs. The “Buses and networks“ division focuses upon industrial communication and the ”Embedded software / automotive systems“ division investigates software issues of modern embedded systems. The latter comprise design methodologies with model-based technologies (e.g. UML). They also include the design of application-specific software architecture (automotive, wireless communication) as well as their tool-based implementation, support for both platforms and development of drivers. Further emphasis is on the development of real-time applications.
In 2004 it also appeared that the synergetic work of the three topical areas is a mandatory factor for the successful completion of projects.
A characteristic feature of the departments’ work is the objective of using free software, which is also known as open-source technologies (Linux, eCos), for the development of customer-specific products. The latest phase of know-how acquisition was completed with a final report in 2004
The practical implementation of the experiences and skills was demonstrated by the commissioning of a Linux-based control system for a high-dynamics mechatronic drive (see page 24). After the successful completion of tests the R&D work towards another embedded control module for the next generation of direct drives has been launched in cooperation with TETRA (Ilmenau) and the Mechatronics division. Further prototype products with embedded Linux have been developed in close collaboration with Thuringian industrial partners. Based on the expertise within the department, Linux ports for microprocessors, that several vendors had requested, were realised. A new and exclusive achievement is the implementation of real-time Linux on the in-house development platform EmLIN, which is an embedded-Linux platform. A practical demonstration has been given at the SPS/IPC/Drives exhibition.

In the field of signal pre-processing and signal conditioning in embedded systems products were realised in cooperation with Thuringian companies. For all these activities a key for efficiency and quality of the development is the consistent use of MATLAB/Simulink as a design entry point as well as the automated code generation for target platforms. Real-time Linux now also counts as one of these platforms. Following the open-source paradigm, the automated code generation was also established in 2004 using Scilab/Scicos (see page 27).
In the field of networking of embedded systems, the essential research results contain the integration of the IEEE 1394b technology (FireWire) for industrial applications into a Linux framework and the triggering of the 1394b hardware via Linux. On the basis of our assumption that wireless near-field networks will become important for future systems, basic investigations were carried out in this field. In 2004, the “Embedded software / automotive systems“ division continued its R&D in cooperation with FALCOM in the field of deeply embedded systems and custom-specific hardware architectures as well as in the development of software applications. Additional workshops and courses on this subject were given. Furthermore, embedded modules for car controls were developed using model-based design tools.
Within the framework of the Ekompass initiative, which is funded by the BMBF, the research project SpeAC II (see page 32) aims at improving the design efficiency by means of employing specification-based methodologies. These activities are closely related to typical examples from practical industry applications.
With regard to other activities for future technologies of signal and data processing a assessment for the 2005 edition of the ITRS Roadmap (Emerging and Research Logic Devices section) was made. This assessment focused on the status and tendencies of the potential for single-flux-quantum circuits for fast and low-dissipation digital applications.
In 2004, a considerable number of students were involved in our project work. The early integration of talented students and their promotion up to dissertation level is crucial for both sides.

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Modular embedded Linux hardware platform

Objective

A basic condition for the development of universal platforms is flexibility. Therefore, modularity was the focus for the development of the universal bus converter EmLIN. The core of the proprietary IMMS design of the embedded system is a processor module with the Net+50 CPU from NetSilicon. This is a processor with ARM7TDMI core but without a memory management unit.
After the completion of the hardware development - [1] - several processor modules, carrier boards and various IO modules exist – the focus of our research increasingly shifted towards the software development in order to create further areas of operation for the EmLIN platform.

Status of the research

Therefore, within the software development we ported the universal U-Boot boot loader for the EmLIN platform. The task of a boot loader is to load and then execute an operating system. Boot loaders exist for nearly all computer systems and their versions.
The best-known boot loaders in the x86 range are, for example, the GRUB, the Lilo for Linux and the nt-loader for windows-based operating systems. In the sector of the embedded systems, the U-Boot project has been established as the quasi standard.
The following items were considered for the practical implementation:

- Correct initialisation of the CPU and the periphery by the boot loader
- Enabling the communication and operation of the boot loader via the serial interface of the CPU in connection with the host system
- Read and write access to the module's flash memory via a driver
- Development of a driver for the internal Ethernet interface of the processor, which realises the boot loader-supported network functionality
- Enabling and testing the booting of uClinux for different configurations

Boot loaders for embedded systems also show some special characteristics, even if the basic functions are the same as for PC systems. This means that the restrictions of an embedded system, for example the memory size, must be considered.

Results

The crease of the flexibility and efficiency for the software development.
For example, an operating system image or another program code can be transferred to the memory of an embedded system and started via a serial connection or via the network interface of the Net+50 processor. For this task no additional hardware, such as a JTAG debugger, is required.
Also, due to the unrestricted access to the system hardware, the developer gets a tool, which significantly simplifies the further development and the troubleshooting of existing software.
Furthermore, the implementation of the real-time application interfaces for the EmLIN module has created the possibility for its use in real-time environments (see page 22).

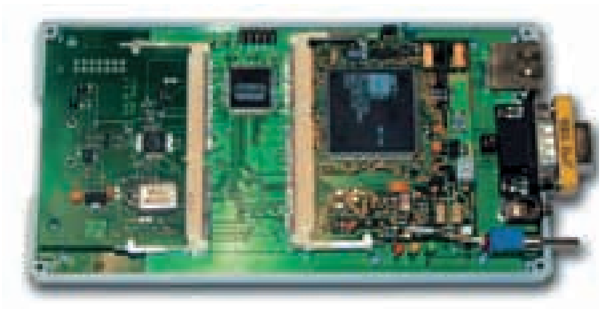

fig. 1: EmLIN3 platform

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[1] Embedded Linux Board EmLIN
(Jahresbericht 2003, S. 26)

Objective

The use of Linux in automation technology is progressing fast. Due to the open kernel source, a wide set of drivers and a relatively quick initial training in driver programming, Linux is an ideal candidate for beginners and programmers of other operating systems. One important aspect in automation is the real-time capability of the employed operating system.
By definition real-time means that a system is predictable in its sequence. The processes must not be disturbed by other processes. With the RTAI and RT-Linux extensions, Linux now also claims to be a real-time operating system (RTOS). In order to secure this claim, RTAI was investigated with regard to its real-time attributes.
In the course of the measurements, many kernel versions, RTAI versions and a few processor types were compared. One important result was that, in contrast to the general assumption that fast processors have better real-time characteristics, it became clear that slower processors can have much better real-time characteristics with regard to latency and jitter than faster ones. The differences are in the processor architecture and in the optimisation of the software for the processor. The results of the measurements give the developers a feeling for the best-suited combination of processor and Linux for their task. The measurements serve as a benchmark and comparison for our own measurements for finding the most suitable processor.
In automation technology many embedded systems with other form factors and lower hardware requirements are used. For these areas of application conventional Linux distributions are too comprehensive.
Also the employed processors have periphery and hardware conditions that are tailored to their subsequent operation. For this purpose special Linux distributions were developed. These distributions are used with a wide range of processors and architectures.
Unfortunately, real-time capacities do not extend to these Linux distributions. However, this feature will become very important in the future. Therefore, we have integrated the RTAI philosophy and applied it onto an embedded Linux.
The development of a real-time system has the following minimum requirements:

- deterministic behaviour
- efficient processing of many external signals like interruptions
- fast reaction, i.e. a small overhead for direct access to physical hardware addresses or for switching to other tasks
- communication with non-real-time systems

On the basis of our RTAI work a real-time extension of the embedded Linux for the ARM processor architecture was developed. A real-time operating system has several basic tasks.
The most important task is probably scheduling and task management.
This includes the efficient management of the real-time tasks that have been divided into tasks or processes.
The operating system is to provide suitable scheduling procedures, which allow a perfect control of all running tasks. Most real-time systems use a priority system for the tasks. Within each priority level the scheduler works according to the Round-Robin or time-slice procedures. Each waiting task is allocated a time interval, in which the CPU controls the task.

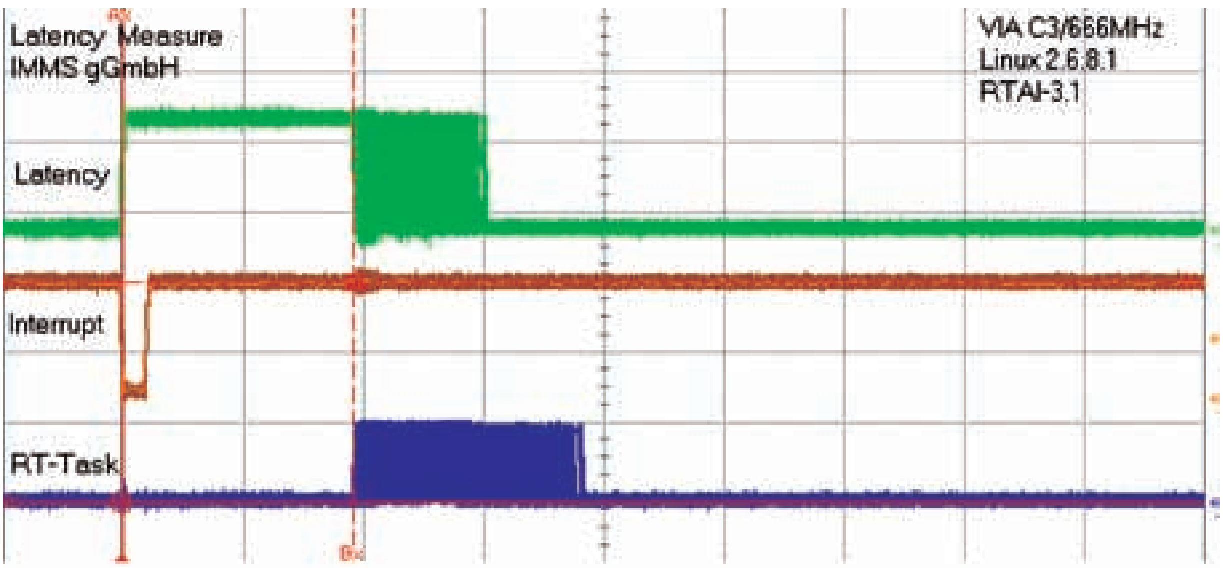

fig. 1: Latency measurement with RTAI

After the time-slice of the task has finished, the scheduler suspends the task and places it at the end of the concurrent task.

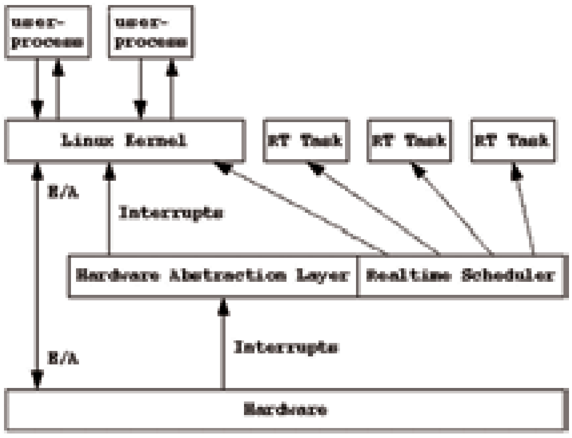

fig. 2: RTAI micro kernel architecture

The use of real-time systems has many advantages. The increasing complexity of many real-time systems can often only be controlled by means of a real-time operating system.
This provides a flexible application interface for a comfortable access to the system hardware. Also, the programming of the real-time software is significantly simplified. If the operating system has standard-conformist interfaces, the applications will gain additional portability, which for example minimises maintenance time for changing parts of the hardware. For this purpose the POSIX standard is required.

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Real-time Linux-based control module for mechatronic drives

Objective

Control tasks in mechatronics can be performed using special controller hardware with customized application software. Currently, another tendency can be observed. The use of an operation system as a run-time environment for the control program introduces greater flexibility because it gives independence from hardware details and a unified user application interface. For many applications the real-time capability, i.e. the guaranteed processing within a tight timeframe, is of crucial importance. In contrast to the use of proprietary real-time operation systems, the deployment of open-source software leads to independence from the vendor. Especially Linux has especially proven its capabilities in industrial environments due to the availability of the code sources and the associated adaptability to the actual operational purpose. Often, for the control of mechatronic drives a deterministic behaviour is required. However, standard operation systems do not exhibit this feature. Several approaches to a solution exist: Usually, they modify the operation system's kernel so that a mini-kernel takes control of the clock maintenance and interruption handling processes.

Status of the research

Under consideration of application-specific constraints, a real-time Linux-based control module was implemented on a single-board computer without a fan. The control system (see figure 1) contains an additional ADC for acquisition of the position data as well as a DAC board for providing the drive control signals.
The real-time capability was realised by means of the well-established RTAI (Real-Time Application Interface) approach. The run-time libraries as well as the procedures that are close to the operation system were customized to fit into a Compact-Flash module. The data conversion and the processing of a control cycle take place within the 200µs clock period. Furthermore, this interval is sufficiently long to allow for user-space programs. These are mainly used for interaction like the monitoring of data or the setting of control parameters. Such user-space operations are not time-critical. They communicate with the kernel-space real-time tasks via a shared memory segment. The access from the user-space is mediated by a socket server. The associated socket clients for the desired action can be activated via the CGI functionality. This allows a web-based operation as a front-end of the entire unit. Figure 2 shows a diagram of the software components of the drive control and their interaction with each other.

fig. 1: Hardware of the developed control unit:
A – single-board computer,
B – D/A converter, C – A/D converter

The replacement of a DSP hardware by this Linux-based solution has shown a way to implement both real-time-capable and cost-effective electronic control units, which are widely usable and easily integrated into existing systems.

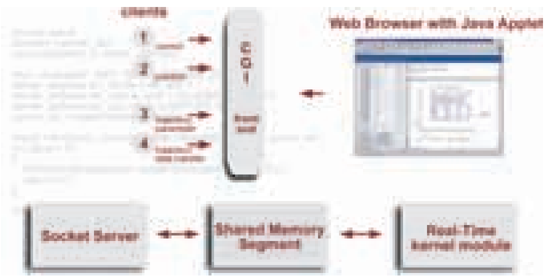

fig. 2: Software components of the Linux-based motor control

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Model-based design with configurable processor core using MATLAB/Simulink

Objective

The field of automation and control engineering shows the continuous trend towards the decentralization and linkage of systems. As a result there is an increasing integration of additional intelligence into sensor technologies in order to achieve both a relief of the control computers and an implementation of standardized interfaces.
Due to increased integration possibilities the design tasks in the area of mixed hardware and software systems become very complex. Usually detailed knowledge concerning the employed hardware is required.
The following approach is based on the design of a model for an abstraction level, where application know-how but no special implementation knowledge is required.
The necessary components for the software and hardware are provided with the help of an automated design flow based on the model (see figure 1). The design flow allows a direct implementation for the target platform.
For the implementation the MATLAB/Simulink design tool was selected because it already contains extensive functional libraries and fulfils the conditions for a code generation.

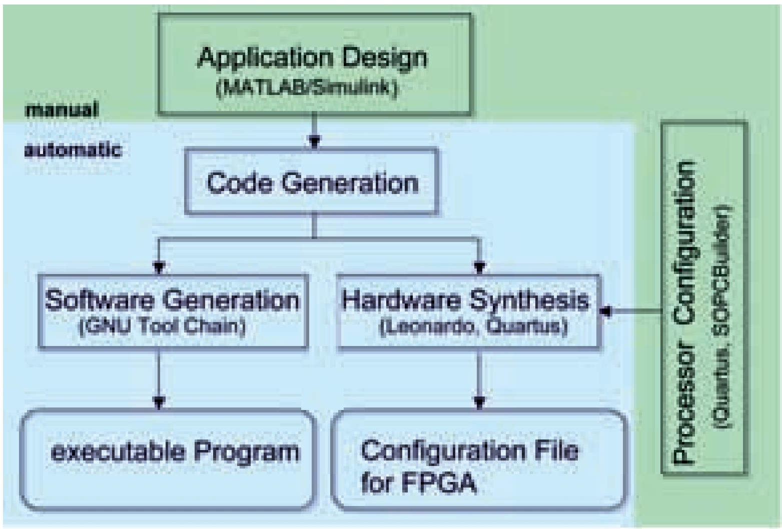

fig. 1: MATLAB/Simulink-based design flow

For the realization of a continuous design flow from the model to the net list or up to the executable program, extensions in MATLAB/Simulink are required.

Status of the research

In the first section the emphasis was on software generation.
MATLAB/Simulink and its Real-Time Workshop (RTW) offer the possibility to generate the C-code from models. The RTW provides so-called targets for different processor architectures. The programme code that has been generated in such a way is not suitable for an automated implementation. For a definite architecture a special target must be developed, which allows an adapted generation of the C-code. Then, the source code can be taken for the production of the executable program without the need for further manual steps.
For the demonstration of the methodology a platform with a configurable processor core (Altera Nios™), freely programmable hardware and other interfaces (analogue and digital) was selected.
Initially, an RTW target for the generation of a code for the Nios architecture, which permits an automated software generation without manual interference, had to be provided.
The essential control of the complete code generation for the model takes place via a target that is specifically implemented for the existing Nios™ platform for use with MATLAB/Simulink and Real-Time Workshop with Embedded Coder. The Nios™ target is based on the well-known Embedded Real-Time Target (ERT) of the Embedded Coder and therefore requires the same conditions (e.g. discrete models only). The main differences to the ERT are the provision of a *main* function and several interrupt service routines that allow an ordered processing of individual functions. The correct integration and initialization of the interrupt service routines, which are in the end responsible for the step-by-step execution of the model, are realized within the *main* function.
Components of the microprocessor (e.g. a timer) as well as external interfaces can be used as sources of interruption. In addition, the generation of a suitable Makefile for compiling the generated C-code and the call-up of special scripts, which implement the *make* programme, were integrated.
Numerous options, both in the interface blocks and in the Nios™ target, enable an extensive adjustment of the simulation as well as the code and software generation to the conditions of the respective application.
For the integration of the signal processing into a test bench (overall system), Simulink models were developed for the interface modules.
With the use of the available Simulink S-functions the behaviour of the analogue/digital or di-

gital/analogue interface was provided as a block in each case. These blocks can be integrated into a Simulink model of the application.
Apart from the accurate simulation of the behaviour of the hardware within the model, subfunctions of the S-function prepare the code generation for the respective interface. The code generation runs by using an interface-associated script and the information made available by the S-function. This enables a large degree of separation between the simulation behaviour and the generation of the source code.
This principle can be applied to arbitrary data interfaces in order to integrate these into the simulation environment and the code generation.
The current level of development permits a model-based design of the signal processing close to the sensor with MATLAB/Simulink for the described architecture. Due to the extensions that have been made no further manual steps after the modelling are required for the generation of the software.

Outlook

The methodology is to be extended by the integration of a code generation for the hardware components within the code design. It is now possible to generate VHDL code for certain FPGA technologies (Xilinx, Altera) by means of special Simulink libraries. However, it is quite possible to produce own extensions of the RTW for the hardware code generation. This has already been implemented for the software part.
In the area of software generation a further abstraction by use of an operating system is planned. For this purpose, preparations including the porting of eCos onto the Nios architecture are under way (see page 28).

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Automated code generation for real-time Linux

Objective

The efficiency of developing a control code as well as its maintenance is mainly dependent on the properties of the design flow. A graphic design entry is a suitable starting point and usually an executable program will result from this approach. Various software tools exist to support this process. They have to be carefully selected and adjusted to each other and to the given task. Usually, time-critical control applications require additional hardware to fulfil real-time requirements. This again affects the choice of tools. The described development work aimed at realising an efficient design flow for real-time Linux as a target platform.
It was intended to use the design-entry functionality as provided by MATLAB/Simulink.

Status of the research

The algorithm itself was to be developed in accordance with the product and is subject to further development within a product line. Therefore, the design flow was developed in a manner that minimised any manual interaction and shifted all main processing tasks onto the level of the structural image. The user interface of choice is MATLAB/Simulink. By means of the Real-Time-Workshop add-on and an existing open-source enhancement, an automated code generation can be achieved in principle for Linux in combination with the Real-Time Application Interface (RTAI). The Simulink-Linux interface contains a set of files with information about the target system as well as auxiliary files for the transfer of the model parameters to the executable code.
In the original version, the communication between kernel space and user space was established via FIFOs. However, for the control of mechatronic drives, the operations, especially the exchange of parameters and the process monitoring, are of a bi-directional nature. Therefore, apart from the adaptation and implementation of the code generator, an enhancement towards the use of shared-memory segments has been implemented. This solution has proved to be versatile and it corresponds to the actual requirements.
Figure 1 shows the Simulink-based design flow for real-time Linux. The starting point is given by the model (*.mdl) that is created by the developer. It is at this level of abstraction that the model-based design of the control application takes place. Specific hardware features like addressing the data acquisition boards can be considered via S-functions.
Guided by a menu, either the C-source code or an executable binary file for the control application can be generated. Initially, an abstract description is created in a pseudo code (*.rtw) in the background, which is then converted into C-code by the target language compiler of the real-time workshop. The binary code represents a kernel module which is loaded into the operation system at boot time.

fig. 2: Graphical user interface of Scicos with a model of a temperature control system. The code generation for RTAI is activated by pressing the corresponding button on the task bar.

Alternatively, an automated code generation for real-time Linux has proved to be feasible with the help of the Scilab/Scicos open-source software package. This package uses a similar internal interface for the conversion from a graphical model into an executable code. Our recent R&D efforts included the evaluation of the potential of this modelling approach and its implementation. Figure 2 shows the graphical user interface of Scicos.

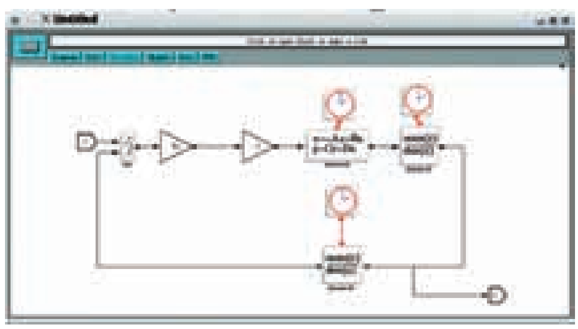

fig. 1: Process of the code generation: Based on a Simulink representation of the designed controller, a binary software module is created according to menu instructions. This software module is transferred to the target platform and activated at boot time.

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eCos as a software platform for embedded devices

Objective

To a growing extent, a major task during the development of embedded devices is the realization of complex applications. By employing an operating system on these devices, tasks can be divided between application and operating system, thus facilitating the implementation and extensibility of the application and improving reusability. With this background IMMS has chosen a suitable operating system for a customer and ported it to various hardware platforms.

Status of the research

As a first step, a suitable operating system was selected - eCos. eCos stands for „**E**mbedded **C**onfigurable **O**perating **S**ystem“. eCos is a **R**eal-**T**ime **O**perating **S**ystem (RTOS) and can be used without having to consider royalties.
Thus eCos is particularly suitable for large scale use. The current version of eCos is distributed under a GPL-compatible license [1]. It guarantees the user the unrestricted access to the RTOS while protecting the application source code from illegitimate use. This way, the company-specific know-how of the eCos user is protected.
eCos has been specially tailored for the limited hardware resources of embedded systems. It consists of various packages, which can be combined for a configuration that is optimally suited to the hardware and the task at hand. Further fine-tuning is possible through configuration options that are provided by the packages. Since the eCos source code is open-source, additional adaptations can be made even on this level. The possibilities of adapting the RTOS to a specific task are almost unlimited. eCos provides all functions [2] that are expected from a modern operating system.
Within the eCos community, this RTOS is continuously being maintained and further developed so that it is well prepared for future tasks. Information is exchanged and support requests are answered via various mailing lists.
In a second step, eCos has been ported to an NEC-based hardware platform and used by the customer. By porting eCos to various ARM-based hardware platforms it was established as a software platform.
Additional applications that are based upon eCos were also developed at IMMS (see page 30).
These positive experiences prompted IMMS to start independently porting eCos onto the Nios platform. In contrast to the processors that had been employed previously, this platform represented an FPGA with a configurable processor core. For this port, the Altera Nios Development Board - Stratix Edition (Stratix 1s10) - was selected as the hardware platform (see figure 1). It offers numerous configurable interfaces, a large variety of input and output options and sufficient memory for complex applications. On this basis, FPGA designs can easily be fitted with an Ethernet interface.
Starting with an existing yet incomplete eCos port ([3], only kernel and HAL), various adaptations to the eCos source code have to be made:

- booting from RAM
- adaptation of memory segments (memory, I/Os, reset vector)
- setting-up of the packages to be used (drivers, configuration data and scripts for providing the sources for the respective target)

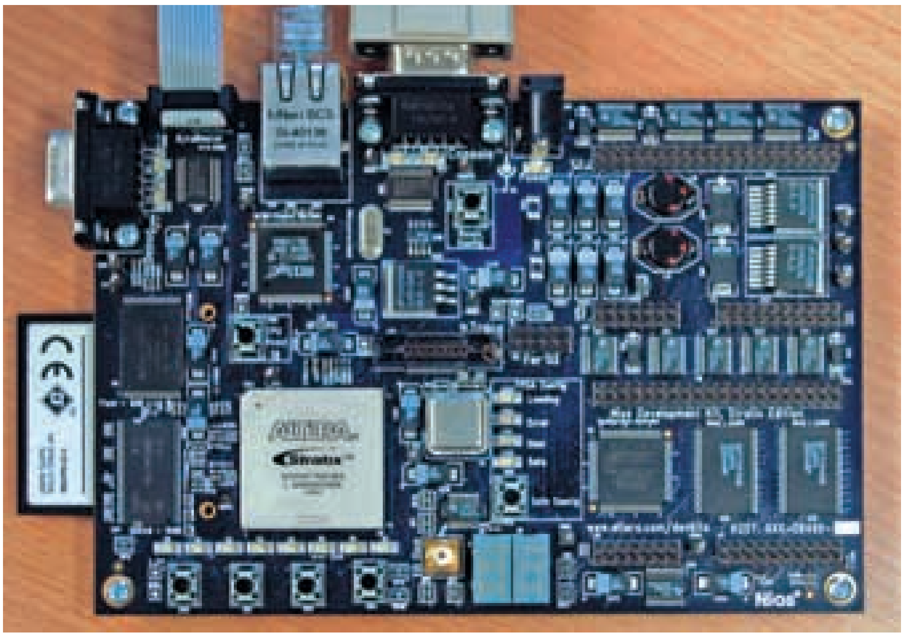

fig. 1: Altera Nios Development Board

Further steps include the creation of a driver (for the LAN91C111 or the Altera Avalon Bus) for the implementation of a TCP/IP stack.
The eCos RedBoot boot loader has already been successfully ported.

Outlook

So far, the customer has successfully introduced the platform strategy for both software and hardware within the company and has deployed it in various devices. Therefore, he is able to benefit from the many advantages of the platform strategy.
During the work on the eCos ports, an increasing interest in eCos was also observed at exhibitions. This indicates that many users consider eCos a suitable RTOS for embedded systems. IMMS is confident that eCos will prove its usefulness also on the Nios platform.

[1] http://ecos.sourceware.org/license-overview.html
[2] http://ecos.sourceware.org/about.html
[3] http://haostudio.idv.tw

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Measurement and transmission of dynamic vehicle parameters using smart wireless communication devices

Objective

The recording and transmitting of measuring data are typical areas of application for smart wireless communication devices (SWCD), which are the focus of numerous R&D activities of IMMS.
A flexible and compact measurement system for automotive applications was developed within the scope of the described project and in co-operation with the department of Automotive Engineering (head: Prof. Augsburg) at Ilmenau Technical University. The project intended to use as many parts as possible of a SWCD hardware/software platform concept, which had been jointly developed with a company called FALCOM.

Status of the research

The department of Automotive Engineering at Ilmenau Technical University has a 1:7 scale model car for teaching purposes (see figure 1). The car is radio-controlled and is equipped with a combustion engine. With regard to the training of students the dynamic behaviour of the car, for example when accelerating or braking or while driving around bends, is of particular interest.
Lab experiments are designed to demonstrate to students the impact of structural engineering actions (e.g. displacing the centre of gravity inside the car) on the driving dynamics of the car.

For this purpose the model car is equipped with a multitude of sensors. Apart from a 3D acceleration sensor the model contains potentiometers for measuring the spring deflection of the four wheels, a sensor for measuring the angle of deviation of the car and a speed sensor (an inductive sensor attached to the so-called Peisler wheel).
Therefore, the project task is comprised of measuring the aforementioned parameters with a reasonable temporal resolution (about 100 values per parameter and second), storing them locally and transmitting them as easily as possible to an external computer (for subsequent analysis).
Furthermore, attention had to be given to the restrictions regarding size and power consumption. The solution incorporated a specific hardware as well as software for the model car and the external computer. The hardware solution is based on an F35-XXL-SI smart communication module from FALCOM.
The module was supplemented by a specific expansion board that provided the input channels for the different measurement parameters. A RS232 port is used for data transmission and features an additional Bluetooth converter for wireless access to the module inside the car.

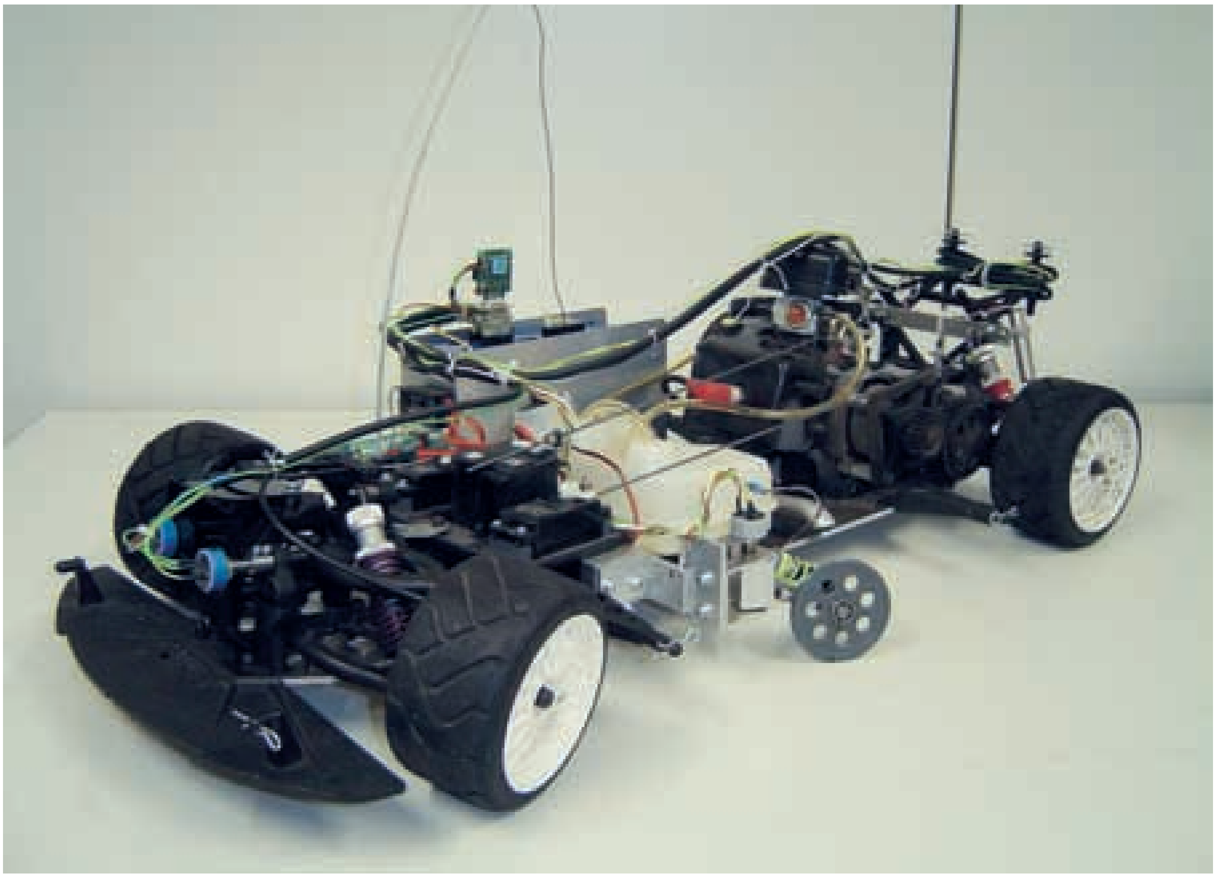

fig. 1: model car

Measuring, storing and transmitting of data values require a software component inside the communication module in the car. The software is a specific application program for the real-time operating system eCos, which is available on the F35-XXL-SI. The software is able to either operate automatically or to be radio-controlled. Certain measurement settings (e.g. measurement frequency) are adjustable via an external computer.
In addition, software for controlling the measurement process and for the convenient transmission of the recorded values was implemented for an external computer. A Java-based solution as well as a native Windows program are available for these purposes.

Outlook

Major parts of the project were carried out by students at IMMS and at Ilmenau Technical University. The model car, together with the measurement system, will be used for lab experiments at Ilmenau Technical University.
There are plans for incorporating additional bus interfaces into the given device concept. Initially, an Ethernet interface and a CAN interface will be realized so that the measuring system can be expanded, for example into an intelligent bus gateway. The software is also to be expanded step by step. The focus will be on the realization of an embedded web server and the application of existing GPS positioning data.

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Codesign of architecture and algorithms with MATLAB/Simulink

Objective

A complex system model, together with a software model, were generated and simulated within the framework of the SpeAC project.
The system model, a pump system with a 3-phase motor without sensors, and the software model, the MLX16 simulator, were joined with MATLAB/Simulink and simulated. The methodology was extended with regard to the use of SystemC as a standardised language.

Status of the research

Traditional design philosophies consider the development of hardware and software as two separate tasks. The software, under the condition of a specification, is implemented parallel to the hardware. Another aspect is the increasing density of information of integrated circuits, which leads to an increase in the complexity of the systems that are to be developed.
Therefore, the system design needs to start on a higher functional level. These designs are called system-on-chip (SoC).
Numerous well-known EDA suppliers from the area of system development support SystemC with a vision of reaching interoperability and improving the design process for hardware/software. Figure 1 shows the general design philosophy for SystemC.

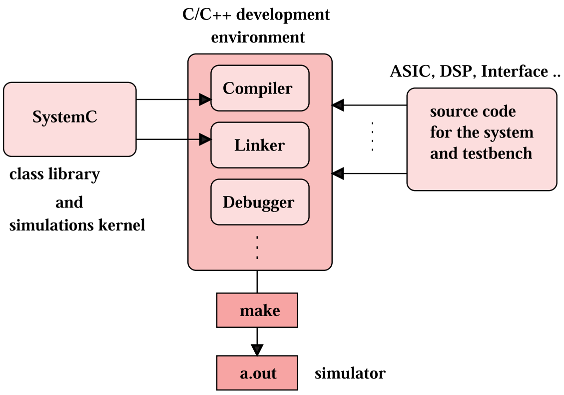

fig. 1: Design philosophy on the basis of SystemC

Modelling requirements

This section investigates the characteristics of system design and verification of SystemC as the example of a definite implementation of a MATLAB/Simulink model. The complete system is part of a pump system with a 3-phase motor without sensors.
This application was realised and simulated under Windows with MATLAB/Simulink. Although the motor model represents an analogue design, it was modelled with SystemC. Figure 2 shows the complete block structure for the design of the motor model.

Initially, each module of Top_Design was simulated in MATLAB/Simulink. Then, the complete structure was programmed under Linux with the SystemC library. The elementary mathematical operations such as multiplication and subtraction or the trigonometric functions sin(x) and cos(x) were taken from the C/C++ library. However, not all of the mathematical operations can be taken from the C/C++ library:
Complex functions such as integration and Laplace transformation are not implement of the C/C++ library. In this case, initially the mathematical format needs to be simplified in order to log it with the help of useable modules. Further, for each mathematical format also the time step needs to be included.
For example, for the Integrator module all values for each time step (t_0 to t_n) are to be calculated.

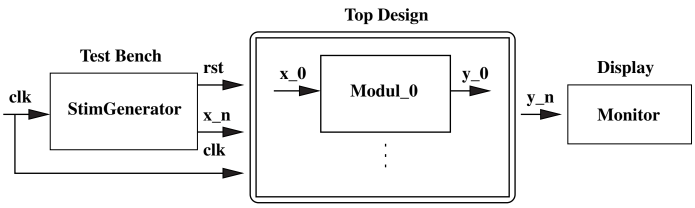

fig. 2: Block structure of the motor model

Part of the reason for the use of SystemC is that the pre-prepared class functions of the C/C++ library can be used as early as during the programming. As an example for the implementation of Simulink functions according to SystemC, the blocks of a general transfer function and of an integrator were used. The transfer function can be written in a general format:

$$y = \frac{1}{lm \cdot s + rm} \cdot U(s) = \frac{1}{lm \cdot \left(s + \frac{rm}{lm} \right)} \cdot U(s) \quad (1)$$

After the retransformation the following differential equation is obtained

$$lm \cdot \frac{d}{dt}(t) + rm \cdot y(t) = u(t) \quad (2)$$

$$u(t) = 0, y(t) = y(0) \cdot e^{-\frac{rm}{lm}t} \quad (3)$$

After the integration this format is already sufficient for further use under SystemC.

The integrator can be formulated in a general format (4):

$$y(t)\int_{t_0}^{t_n} u(t)\cdot dt + y_0 \Rightarrow I_T = \sum_{k=1}^{T} S_k \cdot h \qquad (4)$$

For a fixed step length the result is

$$I_T = \sum_{k=1}^{T} h \cdot S_k = h\sum_{k=1}^{T} S_k \qquad (5)$$

This mathematical format (5) is suitable for the direct implementation in the software.
For these mathematical applications, functions and systems under SystemC can be employed. The notation of *classes* in SystemC is carried out according to the following scheme:

```
#ifndef CLASS_TEST_H
#define CLASS_TEST_H
class class_test
{ private : float test;
public : float funk_lap(float x, float y);
....
}
 #endif
```

The notation of *functions* is analogue:

```
#include 'systemc.h'
#include 'class_test.h'
float class_test :: funk_lap(float x, float y)
{
```

$$test = \frac{x}{A \cdot B} \cdot y;$$

```
  return test;

}
```

Results

The complete SystemC motor model was compiled with the GNU compiler gcc. MATLAB/Simulink was used to compare the results of the MATLAB/Simulink motor model with the SystemC motor model.
The results of the implementation of the motor model in SystemC and in Simulink are shown in figures 3 and 4. The comparison of the implementations does not show any differences..

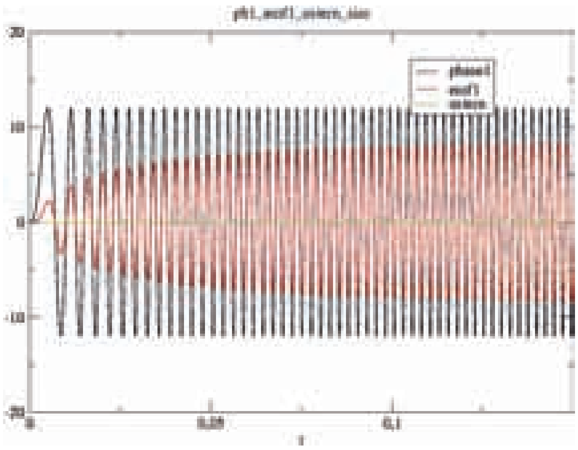

fig. 3: Phase 1, electromotive force 1 (emf) and voltage for the motor triggering - MATLAB/Simulink model

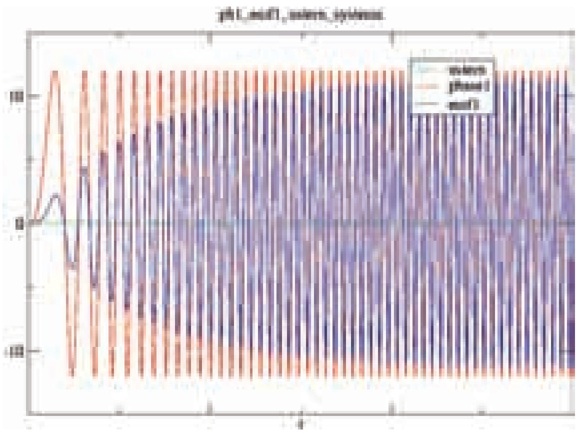

fig. 4: Phase 1, electromotive force 1 (emf) and voltage for the motor triggering - SystemC model

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Accelerated Ethernet topology reconfiguration

Objective

Ethernet as one of the most widespread LAN technologies involves a number of concepts and mechanisms. Building upon basic concepts such as package-oriented data transfer according to the CSMA/CD access method and the identification of network nodes by MAC addresses, an increasing network complexity requires further mechanisms.
Joining several network segments requires the use of so-called bridges. These bridges are used to forward data packages from segment to segment and operate on the link layer of the OSI model. In order to avoid circular routing of packages in such network topologies, an agreement has to be made by all bridges within the network - this regards the paths that are taken by packages between any two network nodes.
This agreement is referred to as (valid) bridge topology and is realized through the communication between the bridges according to a distributed algorithm and an associated protocol, the Spanning Tree Protocol (STP).
In order to ensure interoperability of Ethernet hardware, the relevant mechanisms are specified as IEEE standards. The primary standard for Ethernet bridging is IEEE 802.1d (STP), which has subsequently been extended by IEEE 802.1w (RSTP), amongst others.
Although the STP algorithm specified by IEEE 802.1d effectively fulfils the aforementioned objectives, it still shows deficits.
One significant shortcoming is the comparatively long time that can pass until a valid topology is established after a link has failed. Depending on the specific circumstances, this delay may take 30s or more. It is primarily caused by the fact that the algorithm deliberately waits for a certain time to pass, after which all of the network's bridges are supposed have accommodated the change in topology. Typically, during this time wide sections of the network are unreachable.
IEEE 802.1w attempts to counter exactly this deficit by introducing a bi-directional communication (handshake) regarding topology changes between neighbouring bridges, which may reduce the time that is required to establish a new valid topology down to a few seconds. This is a core aspect of the so-called Rapid Spanning Tree Protocol (RSTP), which is specified by this standard.
In one project, IMMS focused on implementing IEEE 802.1w for the Linux operating system. This was meant to achieve a high accessibility of network nodes despite potential link failures in the context of an application scenario of network-enabled surveillance devices.
These improvements were designed to enable the customer to meet reliability criteria which would not have been possible on the basis of an STP implementation according to IEEE 802.1d. At the point of this report going to print, no other freely available implementation of the RSTP algorithm existed.

Status of the research

IEEE 802.1w primarily consists of extensions to IEEE 802.1d including some modifications. The RSTP algorithm as such is specified both through state diagrams as well as text.
The code of the IEEE 802.1d implementation of the Linux kernel 2.4.19 was used as a basis for the implementation and was subsequently adapted. In the course of the conversion from STP to RSTP the implementation of the bridge's behaviour was completely replaced.
At the beginning of the implementation of the standard at the institute, IEEE 802.1w existed only as a draft. Therefore, the standard's state diagrams were transformed into a clear implementation, maintaining the names used therein and cross-referencing it to the respective section numbers of the standard. This allows the simple association of sections of the code with the corresponding sections of the standard. The run-time deficit compared to an optimized implementation was accepted in favour of improved maintainability and generally considered as negligible.
In order to further optimize the reconfiguration time of the RSTP implementation, a monitoring function of the link status of all ports of the bridge hardware (which is recommended but not specified in detail by the standard) was realized. As a result, failing links can be recognized more promptly. The IEEE 802.1w specifies several configurable parameters with regard to the behaviour of a bridge just as the IEEE 802.1d standard does. These were made configurable via the kernel configuration interface (providing both a textual and a menu-based interface).
Apart from this static initial configuration of the kernel bridge driver, the so-called „bridge-utils" for run-time configuration of the STP implementation are available. In the course of the RSTP implementation, these too have been adapted in order to enable the configuration of those parameters that have been added compared to STP and the suitable retrieval of differing run-time information of the bridge.
The realization of the RSTP implementation has fulfilled expectations in the sense that the bridge topology reconfiguration times were reduced to a range between a few hundred milliseconds and a few seconds, depending on the specific changes to the hardware topology.

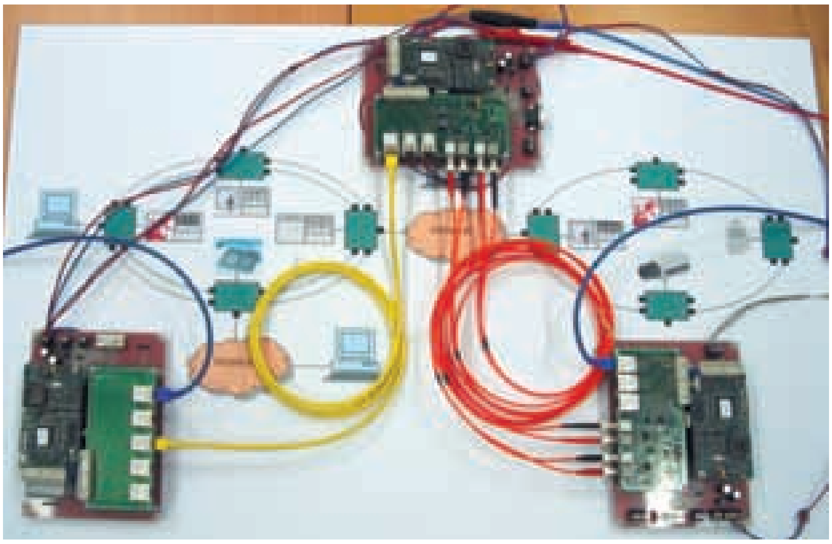

fig. 1: Linux bridge module with 802.1w implementation

Outlook

After the realization and test of the RSTP implementation at IMMS, it is now up to the customer to validate it in practical applications.
If the customer's reliability requirements are fulfilled, it will not only prove that it is a successful implementation by the institute but also that RSTP is superior to STP in a commercial scenario.

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Circuit technology / microelectronics

In 2004 our research work concerning greater efficiency of design procedures was continued. Points of focus were the procedures for optimising analogue systems with special attention to the automation of dimensioning for prescribed circuit topologies, design centring and yield optimisation. The design methods were applied especially for precision analogue circuits, sensor amplifiers, optoelectronic circuits, VCSEL drivers and power-SOI circuits.

Progress was made in the application of the formal verification to mixed-signal systems and hard-ware/software combinations. In the area of simulation electrical/non-electrical mixed systems were examined. This research was significantly funded by the EU and BMBF. We are particularly grateful to the former Thuringian Ministry of Economics, Technology and Labour for its excellent support during the transfer of the researched methods to industrial applications. Our cooperation with MELEXIS GmbH (Erfurt) for research and development of new circuit concepts for DVD reader units and optical busses brought very good results. The circuits that were realised in the X-FAB technology achieved excellent parameters with regard to noise, bandwidth and offset. We tested sensor amplifiers in SC circuit technology. The system architecture and circuit technology for precision analogue circuits were improved and further developed. SOI circuits for Smart-Power circuits, EEPROMs, SRAMs and voltage controllers within a temperature range of up to 300 °C were also tested in practical applications. High-temperature circuits on the basis of the SOI technology became a broad area of competence.

In 2004, our 20 staff supervised and supported the high-level research works and practical training of eleven students. At the same time, we were able to gain six new and highly qualified employees.

In 2004, the department (TB) was able to secure an increasing number of research orders from the industry. We are able to offer this facility on the basis of our application competence for the latest methods and techniques as well as our ability to fulfil the highest demands of compliance with prescribed parameters for analogue circuits under stringent time constraints. Being competent in those areas, demand the generation of special technical solutions, diligence, teamwork, motivation and expert capabilities from our staff. Despite the increasingly difficult conditions for public funding of research projects, these personal characteristics enabled us to further develop the Erfurt institute branch. The traditional cooperation with Thuringian manufacturers of microsystems and semiconductors as well as cooperating with research institutes was further developed and has enabled us to become more independent from public funding – an aspect, which will become very important in the future. In other important projects with the USA and Japan we successfully investigated scientifically uncharted territory and implemented the results in cooperation with the Thuringian microelectronics and microsystems industry.

This growing wealth of experiences forms a very stable basis for the implementation of difficult system development tasks for our industrial partners. The technologies reach from traditional CMOS and BiCMOS to SOI technologies and micromechanical, optoelectronical and magnetic systems. The modular technologies of our industry partners enable us to implement innovative ideas with good parameters. Examples of research projects are:

- Researching the ESD behaviour
- Development of design kits for new technologies (SOI, 0.35 µm BiCMOS)
- Modelling of active and passive integrated elements and parameter extraction
- New analogue basic circuits with improved robustness and parameters
- Design centring, yield optimisation
- Error analysis and optimisation on the basis of symbolic analyses
- Architecture optimisation on the basis of VHDL-AMS and the generated models
- New system simulation methods
- Verification of complex systems
- The guarantee of the testability of circuits
- Optoelectronic and RF measurements
- High-temperature measurements

We would like the reader to regard the described projects as an inspiration and invitation to develop and realise new integrated microsystems and systems-on-chip in cooperation with our institute. The efforts of TB are directed towards the advancement of our Europe-wide and worldwide research work and its industrial application.

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Design of an EEPROM memory in SOI

EU, G1RD-CT-2002-00729

Objective

Over the past couple of years static random access memories (SRAM) have been developed within the framework of the EU development project ATHIS (**A**dvanced **T**echniques for **H**igh temperature **S**ystem-on-Chip) and the SOI subject area. Last year the focus was on the development of an electrically erasable programmable read-only memory (EEPROM), which is to be used in combination with the SRAM in a multichip module.

Status of the research

An EEPROM memory cell consists of a floating-gate transistor (storage transistor) and a select transistor, which allows access to specific cells in a memory cell array.

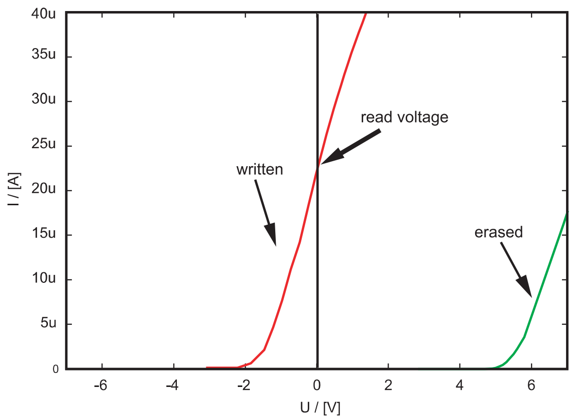


fig. 1: Transfer characteristics of a written and an erased EEPROM-cell

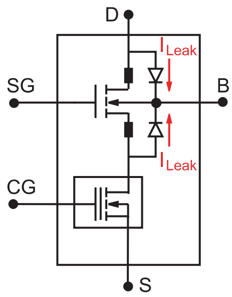
The select transistor has to be a high-voltage device because it has to withstand the programming voltage of 16-18V.

In order to avoid parasitic influences due to the floating-body effect, both the storage transistor and the select transistor have to include body ties, which are provided by film contacts. However, this method induces new problems at temperatures above 200 degrees Celsius, when the increased temperature-induced leakage currents may cause a loss of the stored information in deselected cells [2].

In order to prevent this a new transistor design was developed [3]. This new device is a bidirectional high-voltage transistor with separate body contact directly below the gate. It allows reliable switching in all operating states.

The body will be connected to ground during the read mode and the idle mode, holding the body-to-source diode of the high-voltage transistor in reverse direction.

This will tie down the floating drain of deselected cells to a maximum of one diode flux voltage, reliably preventing charge loss from the floating gate and thereby data loss. During erase and write operations the body must be connected to a voltage lower than VPP and higher than 0V in order to prevent transistor breakdown. A schematic diagram of this novel cell design, together with voltage diagrams for all modes of operation, is shown in figure 2.



	erase	write	read
V_S	0V	floating	0V
V_D	0V	V_{PP}	5V
V_B	floating	floating	0V
V_{CG}	V_{PP}	0V	0V
V_{SG}	V_{PP}+2.5V	V_{PP}+2.5V	5V

fig. 2: Schematic and operating modes of the new EEPROM cell

Measurements have successfully proven the effectiveness of the discussed principle (see figure 3).

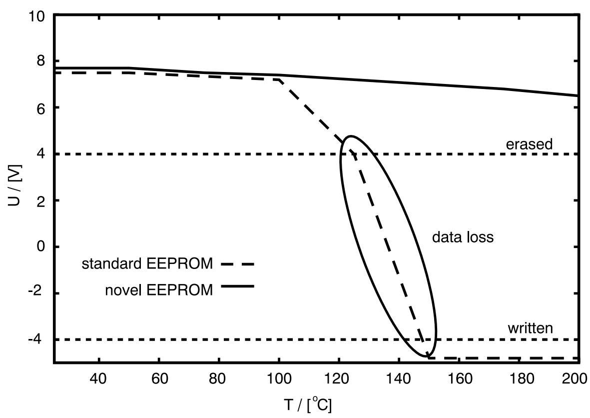


Abb. 3: Threshold voltage shift of erased cells versus temperature for the programming of neighbouring cells

Results

Based on the cell design mentioned above, a memory block has been developed. The crucial points of this design are the voltage level at the select transistor body, the body voltage generation and the memory array design, all of which must consider the body control during different modes of operation. The memory has a modular design allowing for an easy change of memory sizes in order to suit various applications.

All these issues were addressed successfully. A layout of a 32x16 bit EEPROM, which fulfilled all

these conditions, was developed.
The memory cell array and the peripheral devices were designed as standard cells, allowing to assemble the EEPROM modulary and to scale up the memory circuit if required.
The voltage that is applied to the body node is generated internally according to the operational mode. The result is a memory block with a high reliability under harsh operating conditions and very little requirements regarding space.

Outlook

The EEPROM memory will be manufactured during the early months of 2005, followed by a characterisation over the complete temperature range of -40 to 200 degrees Celsius. At the same time, devices that are used for the further development of the EEPROM memory will be characterized. The conclusions that are drawn from the results of these characterisations will be used to redesign the EEPROM memory circuit that is required for the multi-chip module. Two points are important for this redesign, firstly achieving a 5V-only circuit by using a charge pump to generate the programming voltages and secondly reducing the dimensions of the peripheral devices in order to achieve a more compact layout.

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Circuit technology for high-temperature applications

Objective

An important characteristic of silicon-on-insulator (SOI) electronic devices is the possibility for their use at high temperatures up to 250 °C, which is above the normal range for standard CMOS technologies (125 -150 °C).
In cooperation with our industry partner X-FAB (SOI design kit development) we developed analogue cells for high-temperature applications. This paper presents the current state of development with selected examples.

Status of the research

The used technology (XI10) has been optimised for high-temperature operation. For example the threshold voltages have the following values:
at 27 °C - $V_{th,n}$=1.55 V, $V_{th,p}$=1.25 V
and
at 210 °C - $V_{th,n}$=1.1 V, $V_{th,p}$=0.9 V.
We developed a small set of analogue cells,

- band gap
- comparators: n-input, p-input, hysteresis comparator
- operational amplifier
- 10-bit DAC
- 10-bit ADC

and characterised it with measurement technique (department of Industrial Electronics and Measurement Technology, Dr. V. Schulze).
The measuring results confirmed the functionality of the developed devices, especially at high temperatures, which serves as proof for the reliability of the technology and design environment (tools). These IPs (intellectual property) are not only a good basis for the development of further analogue cells but are also suitable for direct use in more complex integrated circuits (ICs).

Results

As an example the results for 2 analogue cells are shown: one 10-bit analogue-digital converter (ADC) and the corresponding digital-analogue converter (DAC), whereby the latter is also available as a separate device (IP). This function is shown in the diagram in figure 1.

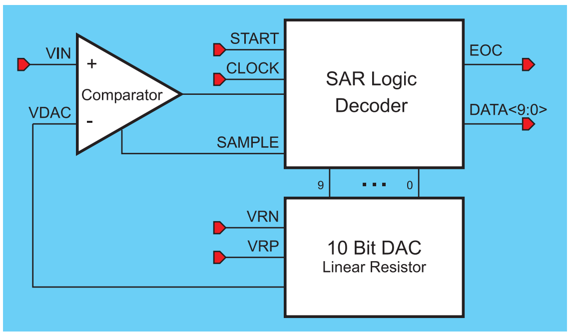

fig. 1: Block diagram of 10-bit ADC

It is based on two linear resistance dividers (two chains for rough and fine resolution) and driven by a successive approximation register (SAR) logic.
The conversion works at an external clock frequency of 1 to 2 MHz and produces sampling rates of up to 200 kS/s (Rsample).
Some typical parameters of the ADC are shown in table 1.

Parameter	value
Temperature range	-40 °C - 225 °C
Resolution	10 Bit
INL	± 1,0 LSB
DNL	± 0,7 LSB
P	4 mW
f_{clock}	1-2 MHz
R_{sample}	90-180 kS/s
V_{RP} - V_{RN}	5 V
Dimensions	1,0 x 0,8 mm

Table 1: Parameters of 10-bit ADC

Figure 2 shows the integral (INL) and differential (DNL) non-linearity of the DAC for four different temperatures:
-40 °C, 27 °C, 125 °C and 210 °C.

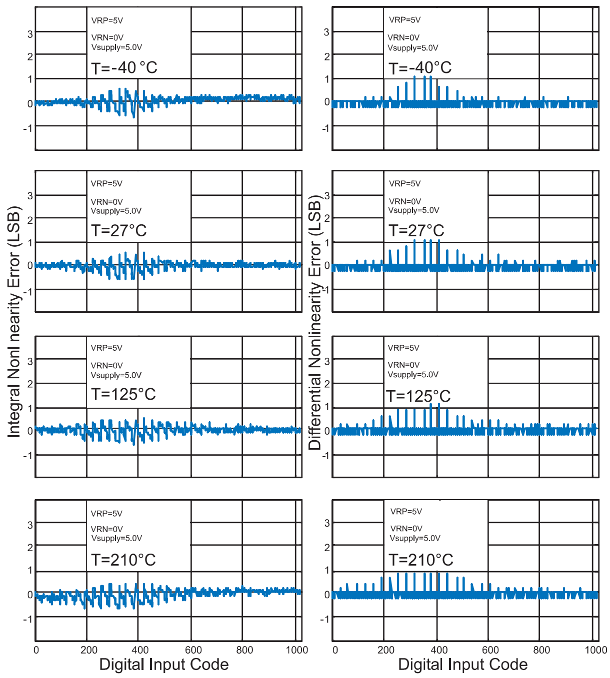

fig. 2: 10 Bit DAC – integral and differential non-linearity

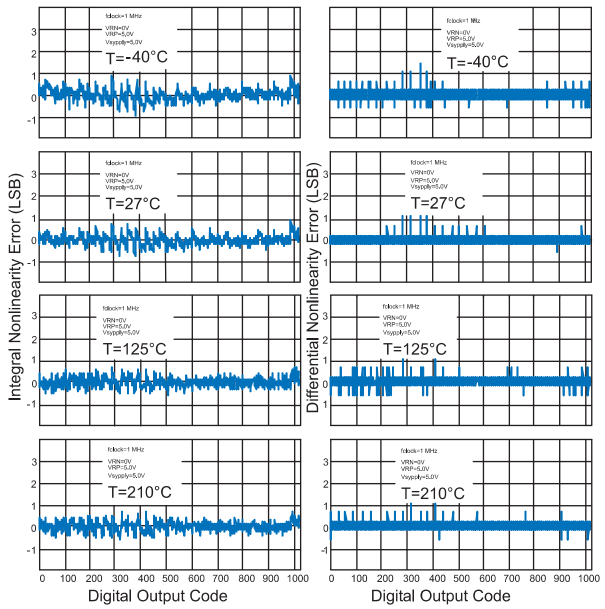

fig. 3: 10-bit ADC – integral and differential non-linearity

Figure 3 contains the respective dependencies for the ADC. A slight improvement of the accuracy of both components can be observed with an increase in temperature. This is due to the decrease of the threshold voltages. This has a positive effect on the switching speeds of the CMOS switches in the resistor chains.

Outlook

The focus of the current and future work in the field of electronic devices for high-temperature applications is on the development of further analogue blocks (IPs) for use in complex integrated circuits for applications in the extended temperature range (from -50 to 220 ºC).

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Configurable interface circuit for capacitive sensors

B 609-01030

Objective

Capacitive Sensors play an increasing role in micro system technology. One reason for this development is the use of modern micromechanical sensors for pressure and acceleration and new principles like stray field capacitors. In order to compete on this expanding market it is necessary to replace the old methods for resistive sensors by developing new readout circuits for capacitive sensors. This is the reason why the TMWFK initiated the CapSens project. IMMS gGmbH works in cooperation with various Thuringian partners (XFAB, Melexis, CiS, IL Metronic, µ-Sen) on this project.

The project objective is the development of a Ttansducer for capacitive sensors consisting of an interface circuit, an ADC and a digital signal conditioning unit. This article introduces the interface circuit for the transduction of a capacitor value into a voltage value.

Status of the research

At the beginning of the project we developed a specification for the interface circuit in cooperation with our partners. The goal of the specification was to create an interface, which can be used for many different applications and increases the possible reuse of the results.

Therefore, we decided to develop a digital configurable interface circuit. Now, the user is able to adjust the circuit to his application demands. The interface was implemented as a switched-capacitor (SC) circuit. This allows a high degree of flexibility, precision and speed as well as the possibility for an integration in standard CMOS. Figure 1 shows the interface consisting of switches, capacitors, OPAmps and external elements (in dashed boxes).

The interface circuit has a total of 11 operating modes. It is possible to read different types of capacitive sensors, for instance differential capacitors, capacitors with ground connection, combinations of a sensor and a reference capacitor and sensors with external stimulus.

The interface can also work in systems with feedback and it is able to read the signal of an external resistive temperature sensor. The following equation shows the connection between the output voltage of the interface and the size of a sensor for a combination of a sensor capacitor and a reference capacitor:

$$V_{OUT} = \frac{V_{REF}}{C_I} (C_S - C_R)$$

The user can also activate up to 4 different correction modes (no correction, offset correction through voltage addition, pseudo-fully-differential mode and the combination of the last two correction methods) depending on the working mode of the circuit. It is also possible to use external integration capacitors and feedback resistors.

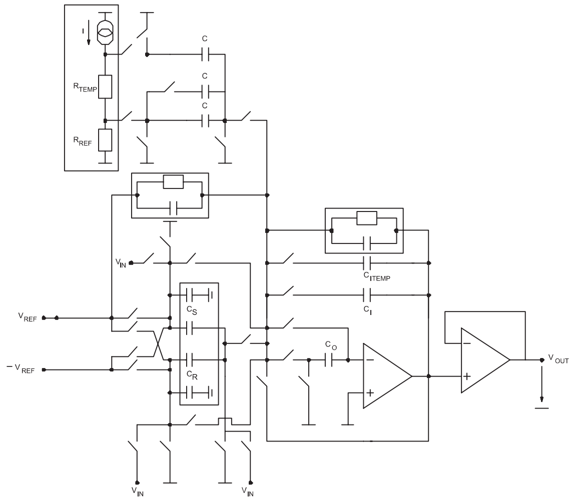

fig. 1: Circuit diagram of the configurable interface circuit

The circuit was implemented in the XC035LV technology of XFAB. Figure 2 shows a chip photograph of the interface. Figure 3 shows the output voltage of the interface circuit for a reference voltage of 1V, a 15pF sensor capacitor and a 10pF reference capacitor. For offset suppression the pseudo-fully-differential correction mode was activated.

Currently we are working on the exact characterisation of the interface circuit regarding linearity and noise.

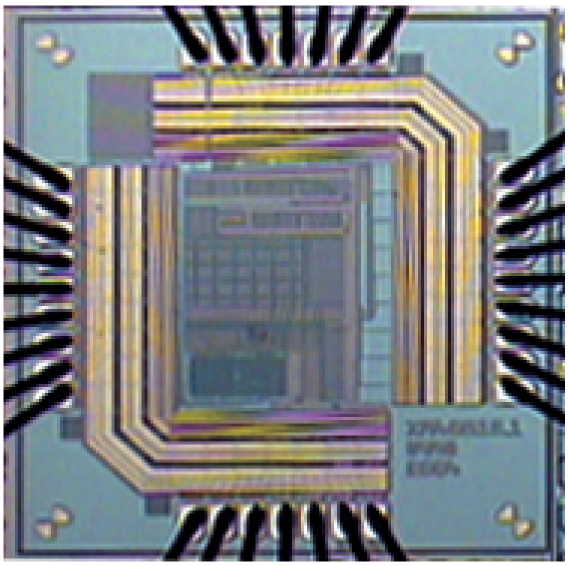

fig. 2: Chip photograph of the configurable interface circuit

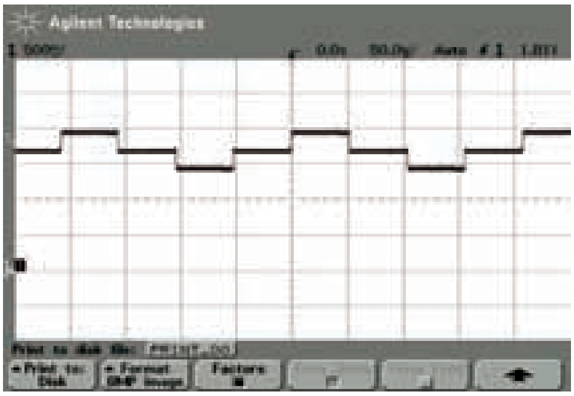

fig. 3: Oscilloscope snapshot of the output voltage of the configurable interface circuit

Outlook

To conclude the CapSens project we intend to combine all developed parts like interface, ADC and signal conditioning unit for the construction of a demonstrator.
This demonstrator will be used as a rapid-prototyping platform for capacitive sensor systems. Furthermore, our project partners CiS and IL Metronic will test the interface in connection with a sensor to prove its functioning in a real application.

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Verification of hardware-near software

Objective

Cars employ an increasing number of small microcontrollers for a variety of simple control tasks. In most cases, these microcontrollers are integrated into the required periphery on a chip. Since these SOCs are increasingly used in safety-relevant applications, their verification has become a mandatory task.
The formal verification of the hardware, which has been established over the past few years, covers only a part of this complex system. Errors in the microcontroller programme for example or in the interaction between hardware and software remain undiscovered. However, for a complete verification the software of the microcontroller must be included.
The VALSE-XT project partners Melexis (Erfurt) and IMMS are developing methods for the formal verification of hardware-near software.

Status of the research

For the formal verification the GateProp tool, which was provided for this project by Infineon, was used. As a microcontroller the MLX16, a 16-bit RISC processor core by Melexis, was used. This microcontroller is available as a Verilog netlist. A brief overview of the project work up to date is given in the following.
The first step was the examination of the basics capabilities of GateProp to process the processor model. It appeared that it was perfectly possible to generate a GateProp-conformist image of the MLX16. After the identification of the internal states, like the phase counter, it was possible to verify individual commands and simple command sequences.
The second step saw the extension of this processor model by a programme memory. This memory is a Verilog description of the ROM content and is generated from a compiler-produced hex file. In another extension stage of the demonstrator a simple RAM model with parameter use was added. This was employed to verify command sequences for 128 individual commands.
However, in order to simulate any hardware influences correctly it is necessary to check the software in its real environment. A circuit for triggering the electrical window motors was chosen as a target system for the examinations. This circuit can be adapted to very different vehicle types and equipment features via the software. Apart from the MLX16, it contains a number of sensor inputs, which enable for example the detection of an obstacle during the closure of the windows. The data exchange with other nodes in the car can be established via a LIN bus.
Figure 1 shows a simplified layout of this chip.
The digital component of this circuit was supplemented by the aforementioned RAM/ROM models from previous research projects. After the implementation of a few modifications of the netlist and a suitable external switching, the digital part by GateProp was processed.
At first, a stable system state after the reset was verified. Based on this state, other arbitrary command sequences within the programme memory can be verified. First tests enabled a verification for 16 commands. However, so far the long computing times have proved disadvantageous.

fig. 1: Sample application for electrical window lift

Outlook

In the course of the future project stages methods for the verification of simple programme examples will be investigated. Furthermore, various simulations to verifications will be compared.
Future computer generations will have to solve the problem of long computing times for the generation of GateProp-conformist simulations in order to cope with rapidly increasing complexities of the coming chip generations.

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Design and characterisation of RF building blocks for X-FAB's design kit using the XB06 technology

Objective

The 0.6 µm BiCMOS technology XB06 offered by X-FAB is suitable for the realisation of radio frequency ASICs for operating frequencies up to 1 GHz. For potential customers, the successful design of RF-ASICs is quite challenging be-cause they often do not have the required know-ledge about integrated RF circuit design and RF measurements.

In order to facilitate customers' entry into the design of RF-ASICs a library containing typical RF building blocks will be created for X-FAB's design kit. The RF building blocks will be fully characterised by measurements so that the ac-curacy of the simulation models is demon-strated and effects that could not be simulated are shown.

X-FAB's customers can then base their RF de-velopments on a library of reliable and charac-terised RF building blocks. For different require-ments, the IMMS can offer to customise existing building blocks or design new ones.

Research progress and results

To allow for a broad range of applications the RF building blocks are functional in a wide sup-ply voltage range from 2.5 to 5.5 V. They are inten-ded for a temperature range from -40 to 125 °C. The ISM band around 868 MHz was chosen as the operating frequency range. The development of the RF building blocks was di-vided into three work packages.

Work package 1 covers the design of a bias cell, which is suitable for RF applications, and fully integrated LC-VCOs. The LC-VCOs employ the integrated inductors and varactors that are avai-lable in the XB06 technology. Three VCO versi-ons of different complexity were realised.

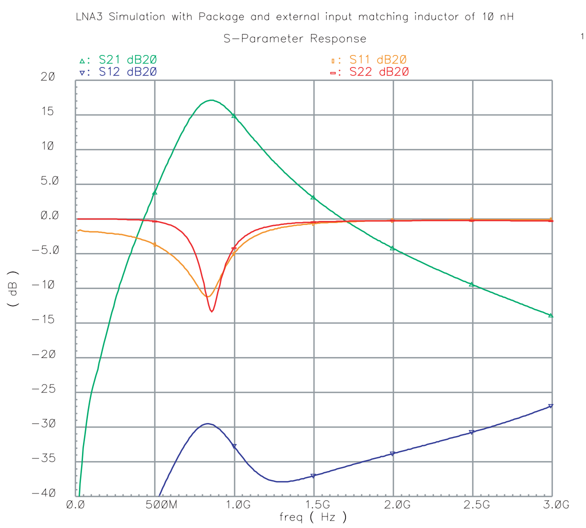

Fig. 2: S-parameter simulation of the LNA test IC shown above, with package model

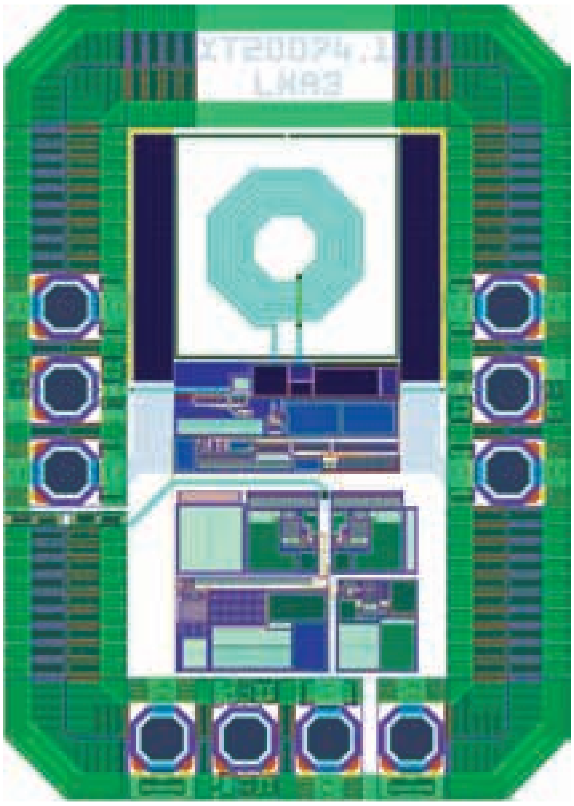

fig. 1: Layout of a LNA test IC

The bias cell and the LC-VCOs have already been processed. Initial tests showed their gene-ral functionality. The detailed characterisation is still being processed.

In the work package 2, a prescaler, LNAs and a ring VCO or relaxation VCO will be created. Four LNA versions for different requirements were re-alised. The prescaler and the LNAs are currently being processed. The VCO is still in the design phase.

Work package 3 contains a power amplifier and a mixer. Work on this work package will start in 2005.

Outlook

In 2005 the remaining building blocks will be de-signed and all building blocks will be fully cha-racterised. For the future, the development of si-milar building blocks for X-FAB's 0.35 µm CMOS technology is planned.

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Industrial electronics and measurement technology

In 2004 one focus was the construction of the test and measurement lab in our Erfurt branch. We started to establish the test of optoelectronic circuits and integrated circuits.
First projects were the test development for dynamic characterisation or linear and area scans of photodiodes respectively. We established cooperation with several new companies at the Applikationszentrum Mikrosystemtechnik Erfurt Südost. The teamwork of IMMS design and test departments was further improved. The equipment for high temperature tests in particular was improved to support the test of SOI devices. In 2005 the test of devices up to 350 °C will be possible. The cooperation with partners in research and industry was extended by joint offers for design and test capabilities. Examples are the design and temperature characterisation of analogue cells and RF demo cells for design kits.
The test and measurement lab in our Erfurt branch has been established as a centre for the collaboration of different departments of IMMS and Thuringian microelectronics and micro systems engineering companies. By moving our Ilmenau branch of IMMS into the buildings of the Ernst Abbe Zentrum working conditions were significantly improved. Now there is much more space available for the test laboratories. One lab has been equipped with a shielded chamber to reduce electromagnetic noise.
This allows us to process new test tasks like the 1/f noise measurement. Initial projects for noise characterisation were successfully finished.
A new wafer prober allows the characterisation of samples in the temperature range of -55 to 200 °C.
We have laid the foundations for a long-term collaboration with partners in research and industry.
Cost effective solutions for test support of cell-Q-devices for X-FAB Semiconductor Foundries were developed. They include the reuse of test hardware and the standardisation of test software. These can be easily adapted to different functional blocks such as I/O-stages, memories in silicon and the power and timing analysis of logic cells for new semiconductor technologies.
The IEM department of IMMS will expand its activities in the area of routine test environment for RF ASIC's and will carry out fundamental research to improve time-to-market and the quality of test developments.
The co-operation with Melexis GmbH grants IMMS access to high-end test systems and handling technology. Both partners benefit from this long-term cooperation, especially for solving complex problems.

The focus of the department for Industrial Electronic and Measurement Technology is on the following areas:

- RF characterisation
- RF noise measurement
- Parameter measurement and modelling
- 1/f-noise characterisation
- Evaluation and test of RF ASICs
- Test of optoelectronic ICs
- Test support for Technology and Design
- Quality assurance for the semiconductor industry
- High-temperature test
- Power electronics for mechatronic drives
- Battery management for lithium ion cells
- Dimmable ballasts for fluorescent lamps

The department for Industrial Electronic and Measurement Technology cooperates with the microelectronics industry of the federal state of Thuringia as well as the whole of Germany. This involves projects that are founded by the BMBF and the European Union.

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Design and RF characterisation of SiC MESFETs

TMWFK, B 607-02006

Objective

An RF test field for the characterisation of SiC MESFETs was developed in cooperation with the Centre for Micro and Nanotechnologies (ZMN, www.zmn.tu-ilmenau.de) and the Institute for Solid-body Electronics at Ilmenau Technical University (www.tu-ilmenau.de/site/fke). This design was part of the project "New material combinations for SiC field effect transistors (NeMaSiC)", which was funded by the Thuringian Ministry of Science, Research and Arts.

Due to its high band gap of 3eV and a high saturation drift speed, the semiconductor material silicone carbide (SiC) allows the realisation of RF components for high performances and high operating temperatures. However, due to the very demanding semiconductor technology, the development of the respective components is still in its early stages. Currently, only very few companies are developing or offering wafers or components on an SiC basis (for example Cree, Inc. / www.reee.com).

Status of the research

A metal semiconductor field effect transistor (MESFET), as it is known from the GaAs technology, is being realised.

We developed a test field, which contains SiC-MESFETs with two different technology and layout versions:

- Implementation of the gate connection via a nitride layer or directly via the buffer layer
- Rectangular or trapezoid layout of the gate connection

Furthermore, the gate lengths of the MESFETs were varied (L_g 1, 2, 3, 5 and 7 µm) while the gate width was kept constant at W=180 µm. The long gate lengths are due to the possibilities of the available technology but are far too long for applicable RF components (as a comparison: the gate length for typical GaAs-MESFETs is clearly below 1 µm).

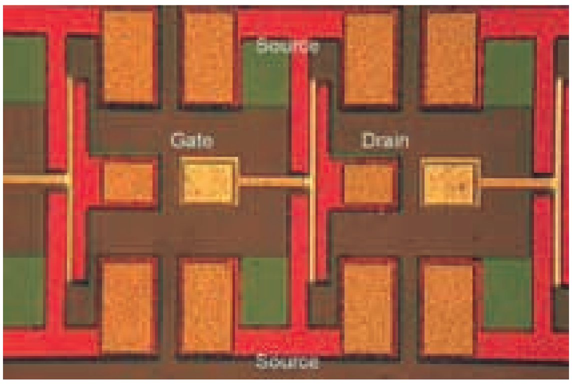

fig. 1: MESFET with connections for probing with GSG measurement tips

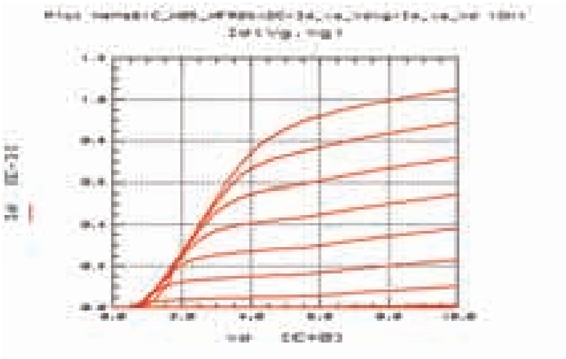

fig. 2: Output field characteristics I_d = f (V_{ds}, V_{gs}) of a SiC-MESFET, L_g= 2µm, W= 180 µm

Therefore, the project objective was merely to demonstrate a functional SiC-MESFET whose limiting frequency cannot be very high because of the long gate length.

A detailed description of the technology that has been used at the ZMN is provided in [1].

In order to carry out RF measurements on a transistor-on-wafer, its connections must be designed in a manner so that they can be reached with suitable measuring tips.

Figure 1 shows a section of the test field with a MESFET whose connections are contactable with GSG (ground-signal-ground) RF probes. This section offers a good view of the different gate lengths as well as the gate feed, which divides the MESFET into two semitransistors. These are in essence coupled in a parallel circuit.

Apart from the transistors themselves, open and short structures were designed, which are needed for the de-embedding. Only the de-embedding allows the determination of the limiting frequencies f_T and f_{MAX}, which characterise the transistor, without the parasite-like influence of feed lines and bond pads.

The measurement was carried out with the HP 85122 measurement system, which is available at IMMS.

It allows DC measurements and RF measurements up to 50 GHz on wafer. For measuring and evaluating, the ICCAP parameter extraction programme is available.

Initially, DC measurements were carried out in order to demonstrate the control effects of the transistor. Figure 2 shows an output field of characteristics with I_d = f (V_{ds},0...10 V, V_{gs}, -3...2 V), as it is typical for MESFETs.

Furthermore, S parameter measurements for different DC working points were carried out at selected components and the reachable limiting frequency f_T was extracted.

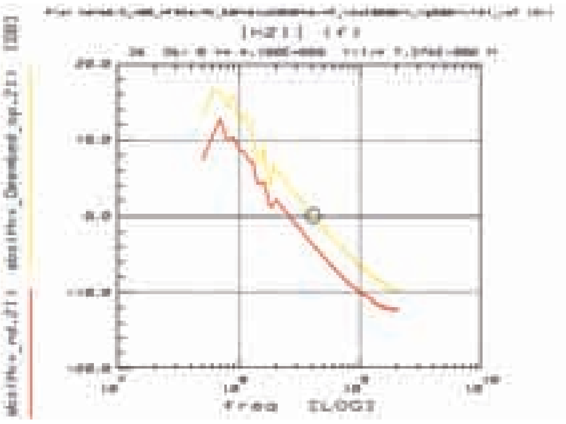

fig. 3: $|h_{21}|$ (f) for a SiC MESFET, L_g= 2 µm, W= 180 µm with and without de-embedding

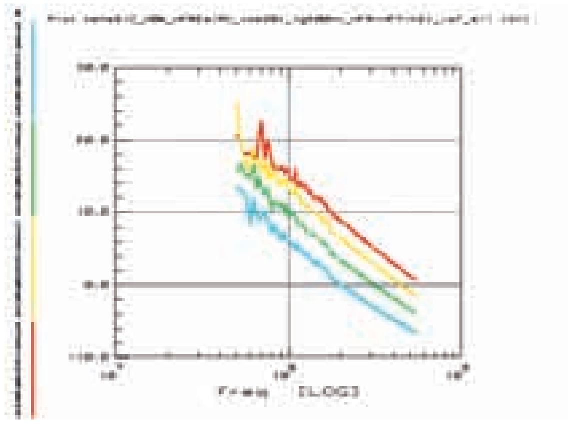

fig. 4: $|h_{21}|$ (f) for a SiC-MESFET , L_g= 2, 3, 5 and 7µm (red/yellow/green/blue)

Figure 3 shows the curve of |h21| (f), from which the limiting frequency f_T results (yellow with/red without de-embedding), as an example for a 2 µm MESFET.
Figure 4 shows this curve again for transistors with different gate lengths of 2, 3, 5 and 7 µm (with de-embedding). This demonstrates the strong influence of the gate length on the limiting frequency of a MESFET:

L_g = 2 µm f_T= 580 MHz
L_g = 3 µm f_T= 437 MHz
L_g = 5 µm f_T= 307 MHz
L_g = 7 µm f_T= 200 MHz

Unfortunately, measurements of the test field showed that, due to the restricted lithographic possibilities, none of the RF transistors with the minimum gate length of 1 µm were functional.
The following table shows the limiting frequencies for different technology and layout versions:

f_T / MHz	L_g			
	2 µm	**3 µm**	**5 µm**	**7 µm**
Gate feed rectangular on buffer	580	437	307	200
Gate feed rectangular on nitride	572	495	290	220
Gate feed trapezoid on buffer	540	422	287	188
Gate feed trapezoid on nitride	602	437	285	205

Outlook

Currently, the SiC technology is still in its very early stages, and so far only very few companies are able to offer SiC wafers or alternative related technology or even SiC components.
We were able to demonstrate that functional SiC MESFETs can be designed and prepared on the basis of the silicon carbide technology, which has been developed at the ZNM.
For a single 2 µm transistor, a maximum oscillation frequency f_{MAX} of 1.3 GHz was measured, which roughly resembles the simulations.
In this respect, we want to point out that this is a totally new technology and that there were no reference values from experience available for the design of the test field including the design rules that were to be prepared.

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[1] Design and technology optimisation as well as process management of SiC transistors); dissertation by C. Fachmann, submitted to the Faculty for Electrical Engineering and Information Technology of Ilmenau Technical University, registry No. 2141- 01D – 04

Noise measurements in EMC-shielded lab

Setup of an EMC-shielded measurement lab with semiautomatic wafer prober

The operation of highly sensitive measuring technology requires a suitable environment (dust-free air-conditioning) because environmental influences can impair the measuring accuracy and the reproducibility of measurements. Apart from these basic requirements, the measurement task demands that the measuring equipment and measuring object are protected from interfering environmental influences (vibration, thermal and climatic influences, electromagnetic fields).

fig. 1: Semiautomatic wafer prober PA200 in shielded cabin

A special problem is the increasing degree of electromagnetic interference, which is generated by so many different devices and services. Mobile phone networks (D1, D2, E-Netz) and radio-based office communication (DECT phone, radio mouse and keyboard, WLAN, Bluetooth) are omnipresent.
The IMMS's move to its new building at the Ernst Abbe foundation on the campus of Ilmenau Technical University offered the possibility to place all the RF measurement technology of IMMS in a specially shielded EMC cabin.
The screen damping is > 90 dB in a frequency range between 0.01 and 26,000 MHz.
The required mains feed power for the operation of the measuring equipment comes via pass-through filters, which guarantee an effective suppression of interference on the network lines. Furthermore, we have the possibility of carrying out all the control processes from outside the cabin via fibre-optic cables, which means that the required computing technology with its PCs and monitors can be placed outside the cabin.
These precautions will ensure that external interference on the measuring objects is to a high extent minimised – a fact that is of special importance for noise measurements. A modern semiautomatic PA200 8“ wafer prober with a thermo chuck from Suss allows temperature measurements from -65 to 200 °C. The additional shielding of the complete chuck with needles or probe holders (probe shield) allows the measurement of minimal currents right down to the sub-fA range. This arrangement makes this prober ideally suited for noise measurements on wafer.

Measuring noise parameters and the 1/f noise

Due to the curve of the noise output density vs. the frequency, often the low-frequency noise is also called 1/f noise. In principle, this measurement is a different measuring task than that used for the RF noise measurement.

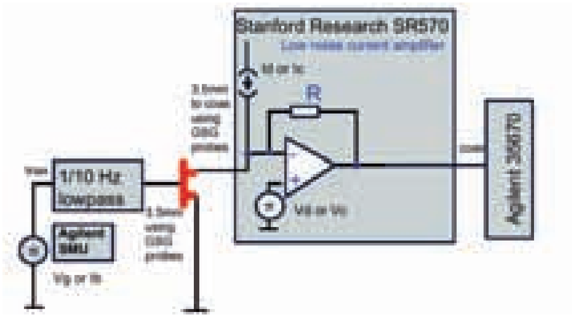

fig. 2: Circuit principle for 1/f noise measurements

The spectral noise output density vs. the frequency is measured with a dynamic signal analyser (FFT analysis). The required low-noise supply of the measuring objects (BJTs or MOSFETs) is carried out via special filters and from an SR 570 low-noise current amplifier from Stanford Reseach. During the measurement, this amplifier is battery-powered in order to avoid any overlaying of the results by noise components from the mains sources. Figure 2 shows the principle of the circuit for a 1/f noise measurement.
Finally, the measurement of the 1/f noise is used for extracting the AF and KF parameters, which are required for component modelling. For the measurement and extraction, the ICCAP parameter extraction programme with the respective noise modelling toolkit is used.
Therefore, the technology, which is available at IMMS, allows a complete noise characterisation.
Apart from the measurement of S-parameters, the determination of noise parameters becomes increasingly important for developing and characterising modern RF components. These noise parameters qualify the transmission behaviour of quadrupoles in real circuits and under near-real operating conditions.

Noise parameters are regarded as the minimum noise figure F_{min}, the optimum source impedance Y_{opt} and the equivalent noise resistance R_n.
The noise figure F of a quadrupole depends on the source impedance, which is offered by the measuring object. Therefore, it is important to provide different source impedances for the measuring objects for the determination of the noise parameters. For this purpose, the electronic tuner system NP5 from ATN Microwave is used.
A corresponding software allows the control of the measuring devices, the acquisition of the measuring values as well as the analysis and visualisation of the results. These noise parameter measurements can be carried out on wafer with two different tuner systems in the frequency range between 0.3 and 6 GHz and between 2 and 26 GHz.

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Evaluation, characterization and test of RF-ASICs

Objective

The experiences in developing RF ASICs are discussed based on the cooperation with Melexis, Erfurt.
They focus on the specific problems of evaluation, characterization and IC test which are described in further detail. Solutions and measurement results are shown for selected examples.

RF ASICs

The trend towards miniaturization requires an increasing degree of integration and results in a higher complexity of the IC design. An optimum solution is not possible with the use of standard ICs. Therefore, the use of an application-specific IC (ASIC) is recommended.
ASICs are special in the sense that a specification, which is described in detail by the customer, has to be met by the manufacturer.

Evaluation

The evaluation of the ICs forms the link between design and production. In order to put the circuit into operation it is necessary to connect it to a PCB. This board must be very similar to the desired application (figure 1).
The external components that are essential for RF ASICs have to be tuned and optimized on the PCB. Therefore, it is essential to use the same components that the designer uses for the simulation and that the customer uses for the final application.
Initially, no data concerning the functionality of the fabricated ICs is available. Therefore, an RF-suitable IC fixture must be used. The same fixture should be used for the production test.
The ASIC shown has been developed by Melexis GmbH. It is designed for passive tire pressure monitoring and torque sensors in automotive applications.

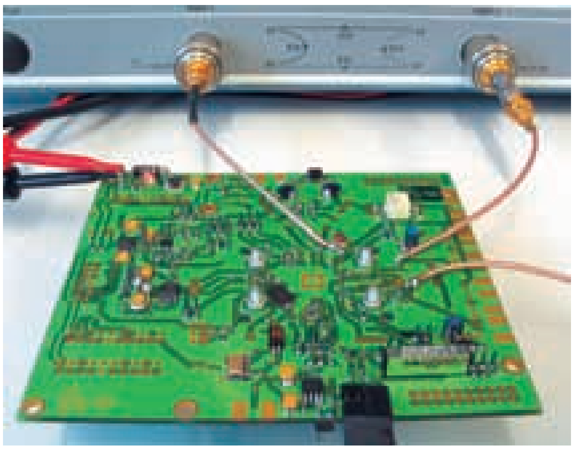

fig. 1: Evaluation board of an RF ASIC connected to a VNA

RF measurements / characterization

The main blocks in such an RF ASIC are receiver (LNA, mixer, IF amplifier), transmitter (PA, modulator) and frequency control (PLLs, VCOs, divider). In order to characterize and evaluate the IC, the following kinds of measurements are required:

- gain / IP3 / selectivity / matching
- sensitivity /signal-to-noise ratio
- spectrum / harmonics / spurious
- phase noise
- lock time, settling time

The variation of the supply voltage parameter and temperature parameter allows the possibility of looking at the worst case scenario (figure 2).
Comparing the results with the simulations allows the calculation of those tolerances in the process of semiconductor production, which could be compensated by design topology.

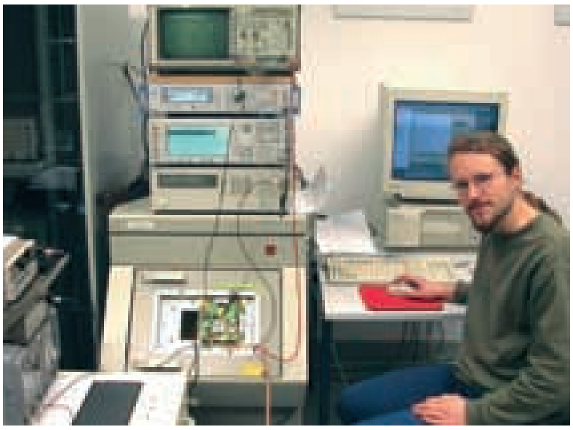

fig. 2: Pre-series tests at the HP82000 tester

Production test

Based on the results of evaluation and characterization it is possible to derive tasks for a possible redesign. Furthermore, these results are introduced into the development of the tester hardware and programming for the production test.

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Optical measurement technology at the IMMS

Objective

The field of optoelectronics contains many applications, which are used for transmitting or storing data. Their increasing use makes it necessary to improve the characterisation of these components. The focus is on the extraction of parameters at photodiodes that change the optical signals into electrical signals. Static and dynamic analyses enlargen the functional range.

Status of the research

On the one hand the test characterisation is possible on the device level. For this purpose, tests can be operated at the optical bench or alternatively a semi-automatic wafer prober can be used to characterize chips on wafer level. This instrument is specifically set up for optical tests.
For the wafer prober this is achieved by an external component on top of the microscope. Here, a XY-table is mounted to issue the optical stimulus for the chip. With this extension the wafer prober can be used for optical measurements.
At the end of the angular arm a coupler for standard FC/PC connectors is installed. Using an optical fibre and a laser it is possible to feed laser light into the microscope.
This configuration allows the movement of the beam spot across to the DUT and the changing of the spot diameter size. The variation of the diameter depends on the magnification of the microscope. By increasing the magnification the spot diameter decreases. In this way a minimum diameter of approximately 1 micrometer can be achieved.

fig. 1: XY table at the wafer prober with optical fibre coupling

The other aspect is the positioning of the spot. The chip can be stimulated at different points while it is contacted by a probe card. This feature requires the XY table. By changing the position of the table the end of the optical fibre is also being moved. Consequently, it is possible to position the beam spot on the chip. The resolution of the XY table is 0.1 micrometer and depending on the microscope magnification it will reach much smaller values.
Figure 2 shows the complete system. It has only one optical input but multiple electrical outputs.
In order to measure the output quantity an oscilloscope or a digital multimeter are used.
One of the most important attributes of an optical device is its sensitivity. This can be calculated by dividing the values of output voltage and input light power. Therefore a small part of the stimulating laser light has to be split off and is measured by an optical power meter. Another problem is the value acquisition at the same time. This can be resolved by using a PC to control the system. This configuration allows to trigger different measurement instruments simultaneously.

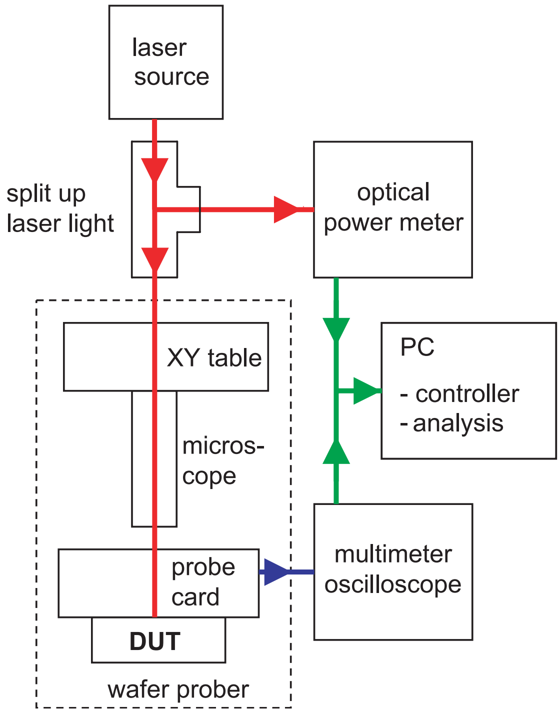

fig. 2: Configuration of the test system

However, the test system should ideally be controlled by another programme. Then, many parameters can be adjusted automatically. The software interface allows the control of the following parameters:

- coordinates of the scanned area
- number of measurement points
- shape of the scan path (parallel, meandering, spiralling)
- instrument selection
- parameters for the XY table (velocity, acceleration, integration time, etc.)

A typical application is an array scan. Here the beam spot is moved across a predefined area. At each point, the spot arrives , the system takes a measurement so that a 3D illustration of the sensitivity can be made.
In collaboration with Melexis in Erfurt different diodes are characterized.

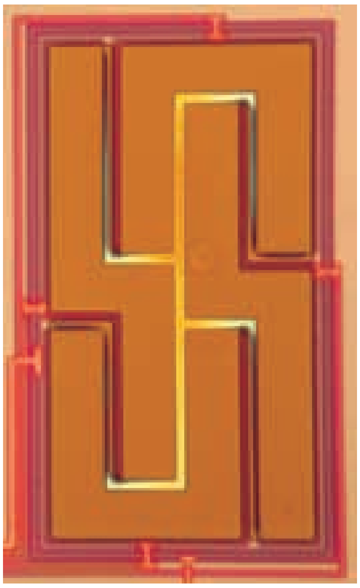

fig. 3: Array of diodes at MLX75002

Figure 3 shows an array of diodes. It consists of four diodes with separate outputs. By scanning the whole area and monitoring only one output the sensitivity variation across the area can be obtained. Therefore it is possible to calculate the crosstalk performance of different diodes. Figure 4 illustrates the result of the described measurement.

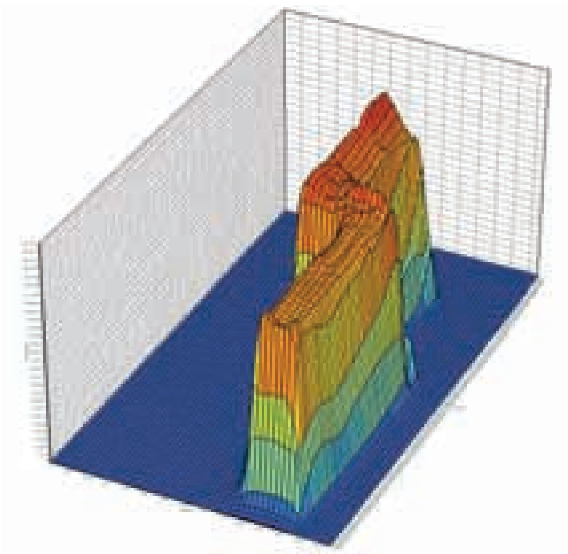

fig. 4: 3D illustration of the sensitivity allocation

Outlook

The wafer prober is to be used increasingly for dynamical measurements. Parallel to these measurements the expansion of measurement options at the optical bench is planned.

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Test support for digital cell quality devices

Objective

So-called cell quality devices (CDQs) are used to ensure the quality of the production process for integrated circuits (ICs) and for parameter tests of standard components for design libraries.
A test and analysis environment that allows the flexible characterisation of digital CQDs in a standard CC68 case with a maximum of 6 power supply pins was developed in cooperation with X-FAB Semiconductor Foundries Erfurt.

Status of the research

The test environment is based on the digital tester HP82000 (figure 1). The tester is equipped with 120 I/O channels with a data transfer rate of 200MHz. A HP6626A system power supply provides 4 power sources that are directly wired to the tester.
Two external source meters, K2400 and K2420, can be connected for IDDQ measurements.
A load board (figure 2) was designed to adapt the device under test (DUT) to the tester. The DUT will be connected by an open-top socket.
The supply pins of the DUT can be flexibly wired by a tester-controlled relay matrix.
In this manner, various supply parameters can be determined. External measurement equipment can be connected via two SMA connectors.
In order to determine temperature-dependent parameters in the range of -55 to 150 °C a Thermostream TP04300 is used.

fig. 1: Digital tester HP82000

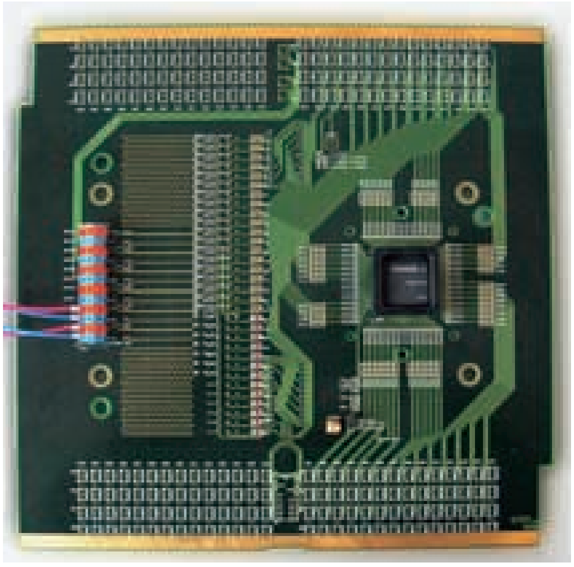

fig. 2: Tester load board for digital CQDs

The whole test environment is controlled by a self-developed VEE program via the GPIB interface. This allows a fast and automated test sequence - only the DUT needs to be exchanged manually. The software automatically generates test reports.
The described test environment was used for the successful characterisation of CDQ.

Outlook

The design of the load board and the development of the software provide the basis for an efficient test support for digital CQDs. The equipment is intended for the verification of I/O stages and memories in silicons as well as for timing analyses and power analyses of logic cells in new semiconductor technologies. For the coming year we have planned the test support for a wide variety of CQDs.

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RF characterization of devices and modules

TMWFK, B 509-03006

Objective

The ever-increasing possibilities in computing are providing reliable results of simulations of devices and circuits.
In order to extract and verify sets of parameters and models it is necessary to realize measurements in the field of RF up to several GHz.
Checking the functionality and the evidence of EMC conformity cannot be done without extensive RF measuring equipment.

Spectrum Analysis

Using these kinds of measurements, the components of a signal vs. frequency can be measured. The equipment operates up to 26GHz. Possible parameters to be measured are:

- frequencies
- harmonics
- spurious
- modulation / power

Additionally features can be used with special options of a spectrum analyzer:

- gain measurements
- noise figure measurements
- compression P1dB / IP3 measurements
- cable distance-to-fault measurements
- phase noise measurements

The phase noise in particular has an essential meaning for the design of oscillators of digital wireless systems. As an example the characterization on wafers of different VCO circuits fabricated by X-Fab, Erfurt, is shown (Figure 1).

Network Analysis

IMMS uses network analyzers up to 50 GHz. In addition to the conventional 2-port devices it is also possible to measure high-frequency S-parameters differentially or symmetrically using a 4-port vector network analyzer. Additional options extend the facilities of measurements:

- gain (magnitude and phase, S21)
- matching (complex impedance, S11)
- frequency response
- compression, SOI, TOI
- mixer measurements
- time domain measurements

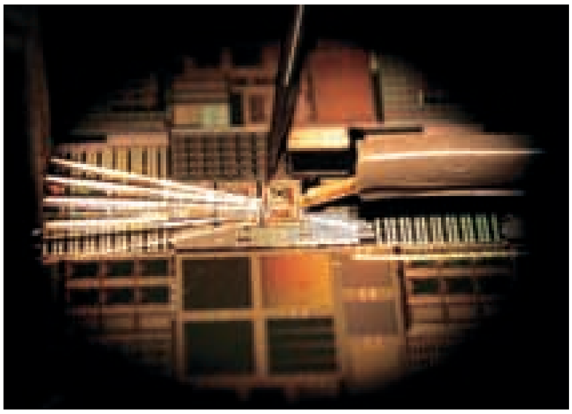

fig. 1: VCO measurements on wafer (X-Fab)

For the publicly funded Thuringian MoDaS (Modular Data Transmission Systems) project, integrated inductors were characterized on wafer. These passive devices will be used in VCOs to generate frequencies in the bands of 900, 2400 and 5600 MHz.

Impedance Measurements

Impedance measurements are to be regarded as part of the network analysis. Using special RLC bridges, measurements like C/V curves can be carried out.

Signal Generation

Various signal generators including I/Q modulators can be used to create signals for modern wireless systems. These are able to generate complex signals of up to 6 GHz.
Analogue modulation as well as digital modulation can be provided by I/Q modulators for several mobile radio standards like GSM, etc.
As an option these generators also include internal arbitrary waveform generators. They serve as a signal source for the base band at low frequencies.
Another feature is the measurement of bit error rates (BER) of digital signals and systems (figure 2).

Time domain measurements

Digital oscilloscopes enable the analysis of waveform of signals of up to 3 GHz.
Equipped with a multitude of features and options, these instruments can realize measurements at the characteristic impedance of 50 ohms or (using probes) single-ended or differential at high impedance.

fig. 2: Characterization using RF equipment

Noise Measurements

A large variety of noise measurements can be done at IMMS:

- *noise parameters:*
  The minimum noise figure F_{min}, the optimum noise matching G_{opt} and the noise resistance R_n are measured.
- *1/f noise:*
  The low frequency 1/f noise of transistors is measured and model parameters are extracted.
- *phase noise:*
  The spectrum and jitter of oscillators are measured depending on the offset to the carrier.

Since all kinds of noise measurement are very sensitive to interference from the environment (RF signals, changes in temperature) they can be carried out in a shielded lab (figure 3).

fig. 3: Wafer prober in the screened lab

Contact systems

All measurements can be realized by using different types of contact systems to connect the devices and modules:

- *coax cables and connectors:*
  Several different coax connectors and adapters can be used: SMA, K, 2.4 mm, BNC, N).
- *test fixture:*
  For planar designs like microstrip or coplanar layouts a test fixture is preferred up to frequencies of 40 GHz (figure 4).
- *on wafer:*
  Measurements on the wafer are possible using RF probes (ACP, coax to air-coplanar), DC needles (single or multiple) or probe cards with many needles of a defined layout. Manual and semiautomatic wafer probers are available at IMMS (figures 2, 3).

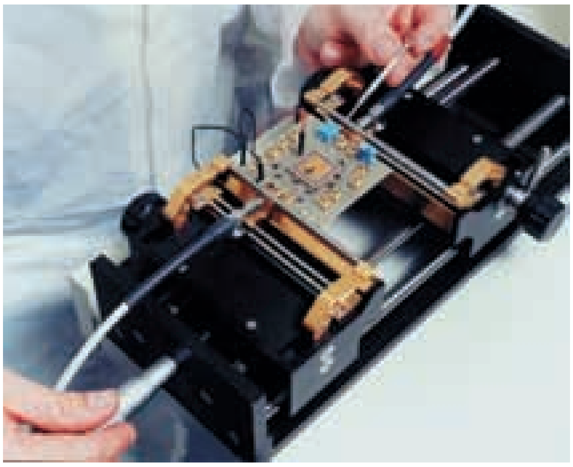

fig. 4: Measurement at RF test fixture

Temperature Range

The measurements can be carried out in the range from -60 to +300 °C. In order to realize this range different facilities are available:

- thermo chuck for wafer prober
- climatic exposure test cabinet
- high-temperature oven
- thermo stream

We have gained extensive experience of special assembly technologies for high-temperature applications.

Outlook

This abstract provides only a brief overview of our measurement facilities. Our focus is on special measurement technologies. Most of the measurements can be carried out in the time domain or frequency domain. At IMMS our objective is to find the optimum solution.

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Memberships in associations, special groups, etc.

- **1394automation e. V.**
- **AMA Fachverband für Sensorik e.V**. - *Wissenschaftsrat, Fachausschuss „Mikrosystemtechnik und optische Sensorik“*
- **American Chamber of Commerce**
- **automotive thüringen e. V.** - *Automobilezulieferer Thüringen e. V.*
- **DFAM** - *Deutsche Forschungsgesellschaft für die Anwendung der Mikroelektronik e.V.*
- **DFN** - *Deutsches Forschungsnetz*
- **EIBA** - *EUROPEAN INSTALLATION BUS ASSOCIATION*
- **EUROPRACTICE** - *European Commission initiative*
- **Fraunhofer Gesellschaft** / IOF Jena
- **Mitglied 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)
- **GI/GMM/ITG-Kooperationsgemeinschaft „Rechnergestützter Schaltungs- und Systementwurf (RSS)“**
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- **GMM** - Beirat
- **GNT** - *Gesellschaft zur Förderung neuer Technologien Thüringen e. V.*
- **IEEE** - *Circuit and Systems Society; Electron Devices Society; Solid-State Circuits Society*
- **InnoRegio Südthüringen e. V.**
- **ITG-Arbeitskreis** - *„Zusammenarbeit Industrie und Hochschulen“*
- **ITG Fachgruppe** - *„CAD für den Analogschaltentwurf“*
- **Lernende Region Ilm-Kreis**
- **Linux LIVE Verband e. V.**
- **Mitglied des „Inneren Arbeitskreises“ FUTUR des BMBF**
- **MSDN** - *MICROSOFT DEVELOPERS NETWORK*
- **MTT Mikrotechnik Thüringen e. V.**
- **OptoNet e. V. Thüringen** - *Fachgruppe Optoelektronik und Bildverarbeitung*
- **Silicon Saxony e. V.**
- **Steuergremium des EDAcentrums**
- **TZM Erfurt** - *Technologie-Zentrum-Mikroelektronik e. V.*
- **USB** - *Implementer Forum*
- **VDE / VDI** - *Fachgesellschaften ITG, EKV und GMM*
- **VDE / VDI** - *Arbeitskreis „Mikrotechnik Thüringen“*
- **VDMA** - *Arbeitskreis „Nutzergruppe Mikrosystemtechnik“*
- **VSIA** - *VITAL SOCKET INTERFACE ALLIANCE*

Publications / Papers / Lectures / Research Reports / Patents

- **A new tool for industrial tribology - Filling the gap between macro- and nano-tribology**
  Achanta S., Drees D., Celis J.-P., Mollenhauer O., Dr. Spiller F. (IMMS gGmbH); 14th International Colloquium „Tribology and Lubrication Engineering"; 13.01.-15.01.2004, Esslingen

- **OPV und TIA-Optimierung mit WiCkeD**
  Dr. Boos V., Lange St.; Workshop „Effizienzsteigerung und Ausbeuteverbesserung im analogen Schaltungsentwurf mit WiCkeD"; 20.01.2004, Erfurt

- **Echtzeitsteuerungstechnik für hochdynamische Antriebe**
  Dr. Töpfer H., Braczek M., Elste Th., Grunert S., Dr. Schröder Ch.; Workshop „Innovative Produkte im Spannungsfeld von Entwicklung und Vermarktung"; 23.01.2004, Ilmenau

- **Elektrodynamische Antriebe für die Mikro- und Nanotechnik**
  Dr. Schäffel Ch.; Workshop „Innovative Produkte im Spannungsfeld von Entwicklung und Vermarktung"; 23.01.2004, Ilmenau

- **Faseroptische Kommunikation nach IEEE 1394b über Phaseroptische Fasern**
  Dr. Töpfer H.; 18. Fachgruppen ITG-FG 5.4.1. „Optische Polymerfaser"; 09.03.2004, Erfurt

- **Modellierung von Mikroprozessoren mit MATLAB/Simulink**
  Hahn M.; Fachzeitschrift „Design & Elektronik"; Ausgabe 02, S. 40 ff

- **Evaluierung, Charakterisierung und Test von HF-ASICs**
  Bieske B., Dr. Förster K.; 3; 2004; ITG/GI/GM; 29.02.-02.03.2004, Dresden

- **Steuerung elektronischer Antriebe mit RTAI**
  Dr. Töpfer H.; Linux-Automation-Konferenz 2004; 04.-05.03.2004, Hannover

- **Flexibler Buskonverter mit µC-Linux**
  Peukert R.; Linux-Automation-Konferenz 2004; 04.-05.03.2004, Hannover

- **Dynamic measurements on organic FETs**
  Hörselmann P., Dr. Kornetzky P., Herasimovich A., Dr. Scheinert S.; Frühjahrstagung des Arbeitskreises Festkörperphysik (AKF) der DPG; 08.03.-12.03.2004, Regensburg

- **Silicon-On-Insulator circuits for application at high temperatures**
  Dr. Nakov V.*, Dr. Nuernbergk D.*, Richter S.*, Bormann St.*, Dr. Schulze V.* (*IMMS gGmbH), Richter S.; Workshop „SOI NATO Advanced Research"; 25-30.04.2004, Kiev, Ukraine

- **A novel low leakage EEPROM cell for application in an extended temperature range (-40°C up to 225°C)**
  Richter S., Dr. Nuernbergk D.*, Kirsten, D.*, Richter S.* (*IMMS gGmbH); Workshop „SOI NATO Advanced Research"; 25-30.04.2004, Kiev, Ukraine

- **Dynamische, mechatronische Motorsteuerung - Echtzeit-Linux zur Ansteuerung hochdynamischer Direktantriebe**
  Dr. Schröder Ch., Dr. Töpfer H.; Fachzeitschrift „Elektronik"; Ausgabe 09, S. 86 ff

- **Noise behaviour of aerostatic bearings for Ultra-Precisions Stages**
  Dr. Schäffel Ch., Hesse St.; 4th euspen International Conference and 6th Annual General Meeting, 30.05-03.06.2004, Glasgow / England

- **Planar Motion System for a Nanopositioning- and Nanomeasuring Machine (NPMM, NMM) with 200x200m² operating range**
  Dr. Schäffel Ch., Hesse St., Mohr H.-U.; 4th euspen International Conference and 6th Annual General Meeting, 30.05-03.06.2004, Glasgow / England

- **Intelligente Datenerfassungs- und -übertragungsmodule für den Einsatz in Personen- und Nutzfahrzeugen**
  Kattanek W.; automotive thüringen e.V.-Workshop „High-tec im Auto"; 16.06.2004, Ilmenau

- **Aspekte der Systemintegration von supraleitender Hochgeschwindigkeits-Digitalelektronik**
  Dr. Töpfer H.; „Kryo 2004" Kryoelektronische Bauelemente; 12.-14.09.2004, Goslar

- **RSFQ Logic Devices**
  Dr. Töpfer H.; ITRS-Roadmap „Emerging and Research Logic Devices" Workshop; 24.09.2004, Leuven / Belgien

- **High-speed optoelectronic interface for RSFQ superconductive electronics**
  Badi S., Febvre P., Eusebe H., Roux J.F., Coutaz J.L., Krotkus A., Ebert B., Dr. Töpfer H.*, Ortlepp,Th.* (*IMMS gGmbH), Uhlmann F.H., Kunert J., Fritzsch L., Meyer H.-G.;
  5th SCENET School „Superconducting Materials and Applications"; 30.08.-10.09.2004, Salamanca / Spanien

- **Vernetzung intelligenter Knoten im Automatisierungsbereich auf Basis neuer Betriebssysteme und Bustechnologien**
  Pietrusky J. (IMMS gGmbH), Dr. Arlt St.; Abschlussbericht Intelli-Net-Projekt, FKZ: B 609-99023, Ilmenau

- **Modulare Präzisionsantriebe für MEMS und Laserfertigung**
  Mollenhauer O., Dr. Spiller F. (IMMS gGmbH), Pause, S., Rode, D.;
  Statusseminars zum Verbundprojekt „MODAN";
  VDE/ VDI-Tagung „Elektrisch - mechanische Antriebssysteme"; 06.-07.10.2004, Fulda

- **A 900-MHz Fully Integrated LC-VCO for ISM Applications**
  Teichmann P. (IMMS gGmbH), Peter J., Dr. Laute A.; European Conference on Wireless Technology; 11.-12.10.2004, Amsterdam/Niederlande

- **Linux und Echtzeit ohne MMU**
  Peukert R., Elste Th.; Fachzeitschrift „Elektronik - SOC System on Chip"; Ausgabe 10, S. 16 ff

- **Designing a Low-Noise VCO**
  Dr. Laute A., Peter J., Teichmann P. (IMMS gGmbH); Fachzeitschrift „Microwaves & RF", Ausgabe 11

- **Design Methodologies for Flux Quantum Circuits**
  Dr. Töpfer H.; 336. WE-Heraeus-Seminar „Processing of Quantum Information in RSFQ Circuits and Qubits"; 29.11.2004, Bad Honnef

- **Design of a Superconductor-to-Semiconductor Interface Circuit for High Data Rates**
  Ortlepp Th., Schwemlein R., Flamm J., Wünsch S., Crocoll E., Dr. Töpfer H. (IMMS gGmbH) Uhlmann, F.H., Siegel. M.; 336. WE-Heraeus-Seminar „Processing of Quantum Information in RSFQ Circuits and Qubits"; 29.11.2004, Bad Honnef

- **Technology and Design of RSFQ Circuits for Operation at High Temperatures**
  Cassel D., Ortlepp Th., Ilin K.S., Pickartz G., Kuhlmann B. Dittmann R., Klushin A., Dr. Töpfer H. (IMMS gGmbH), Uhlmann, F.H., Siegel. M.; 336. WE-Heraeus-Seminar „Processing of Quantum Information in RSFQ Circuits and Qubits”; 29.11.2004, Bad Honnef

- **Heterogeneous multi-abstraction level simulation and co-simulation**
  Ulicna E.; MEDEA+ A508 SpeAC Meeting; 30.11.2004 Paris

- **Modellbasierter Entwurf mit konfigurierbarem Prozessorkern**
  Zellmann J.; Fach- und Kooperationsworkshop „MATLAB-Integration und Performanceanalyse“; 08.12.2004, Dresden

- **Signalverarbeitung digitalisierter Sensorsignale eines Smartsensors in MATLAB/Simulink für FPGA-Implementierung**
  Ulicna E.; Fach- und Kooperationsworkshop „MATLAB-Integration und Performanceanalyse“; 08.12.2004, Dresden

- **Bi-Decomposition of Function Sets in Multiple-Valued Logic for Circuit Design and Data Mining**
  Lang Ch., Steinbach B.; Artificial Intelligence in Logic Design (Ed. S. Yanushkevich), Kluwer Academic Publishers, S. 73–107, 2004

- **Exploiting Functional Properties of Boolean Functions for Optimal Multi-Level Design by Bi-Decomposition**
  Steinbach B., Lang Ch.; Artificial Intelligence in Logic Design (Ed. S. Yanushkevich), Kluwer Academic Publishers, S. 159–200, 2004

- **Bi-Decomposition of Function Sets using Multi-Valued Logic**
  Lang Ch.; Ausgezeichnete Informatikdissertationen 2003 (Hrsg. D. Wagner et al.), GI-Edition Lecture Notes in Informatics, S. 111–119, 2004

- **Patent DE10303643**
  „Verfahren zur Herstellung von Substratkontakten bei SOI-Schaltungsstrukturen”
  Steffen Richter, Wolfgang Göttlich, Dr. Dirk Nuernbergk

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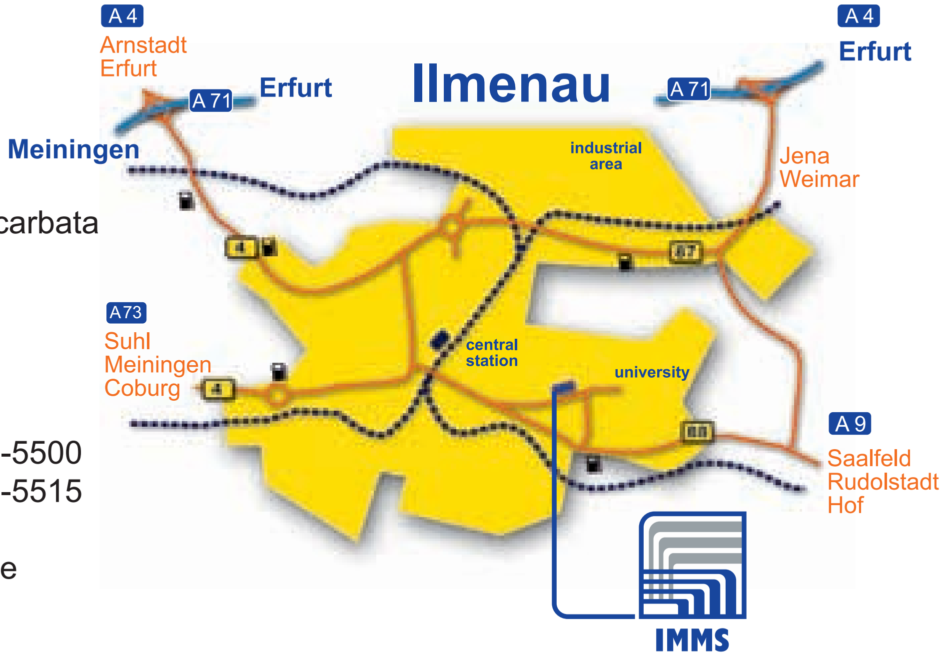

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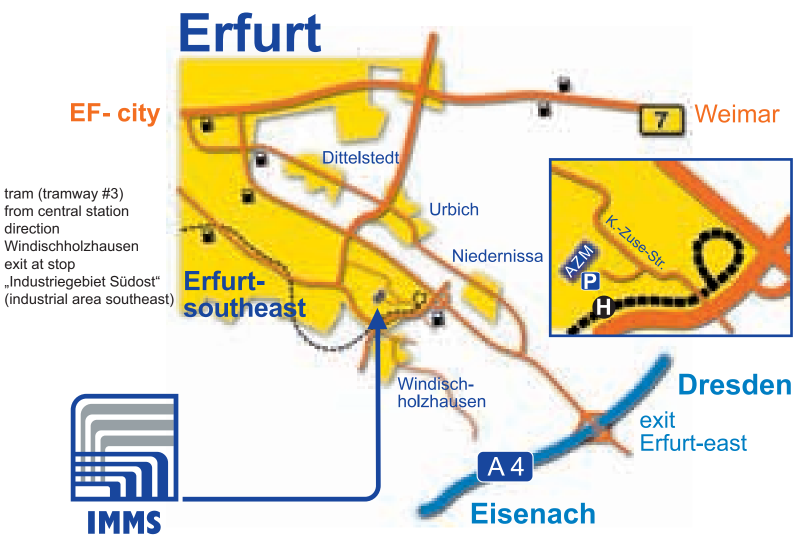

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