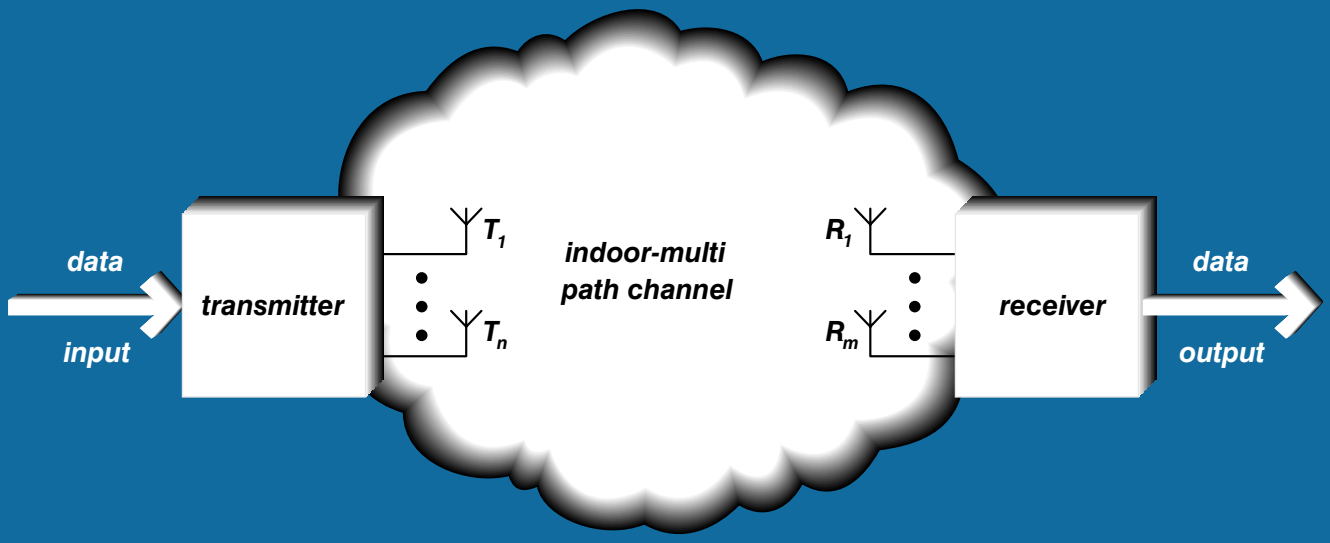
HEINRICH-HERTZ-INSTITUT



Multiple Input • Multiple Output

MiMo

Radio System for Wireless Local Area Networks

REPORT 2001

HEINRICH-HERTZ-INSTITUT

REPORT 2001

HHI REPORT 2001

Editorial coordination:
Regina Kiesewetter
Language consultants:
Ingeborg and Harvey Holmes
Layout and typesetting:
Zühlke Scholz & Partner
Werbeagentur, Berlin
Printing:
Druckhaus Mitte, Berlin
ISSN 1435-1587

Heinrich-Hertz-Institut
für Nachrichtentechnik
Berlin GmbH,
Einsteinufer 37, 10587 Berlin

Cover illustration:
The multiple reflected radio waves in indoor environments arrive from all directions like light, which is scattered in a cloud. Information theory shows that such radio channels offer an enormous transmission capacity, which is advantageously exploited by multiple-imput multiple output (MIMO) radio systems.

New mathematical techniques for the design of multiuser MIMO systems were developed at HHI. Prof. Dr Dr Holger Boche received the PhD-award of the "Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz" for his mathematical contribution in this research area.

TABLE OF CONTENTS

TABLE OF CONTENTS

FOREWORD

The year 2001 was marked by preparation for the Institute's integration into the Fraunhofer society (FhG). The most important prerequisites for the transfer of the ownership of the HHI are now fulfilled, and this transfer should be complete by the end of March 2002, when the Fraunhofer Society will become the sole shareholder of the HHI.

The starting point for the integration of the HHI into the FhG stems from the strategy of the German government for the domain of information and communication technology (ICT):

- It is the goal of the Federal Government to bring ICT research in Germany to a leading position in Europe in order to create new, sustainable employment opportunities.
- The present high levels in basic research and in the development of novel applications of ICT shall be maintained and further expanded.
- To this end, government-sponsored research in ICT will be concentrated in the FhG to facilitate the swift transformation of research results into products.

The following reasons were decisive for the executive management of the HHI when deciding to approve and further this integration:

- The goals of the Federal Government concerning ICT research are of great relevance for the national economy and are a great challenge for science and research.
- The FhG will become the leading centre in ICT R & D in Europe. As a member of this centre, the HHI will have a central role in the creation of the future of ICT in Europe, whereas otherwise its role would be of only minor importance.
- The R & D fields pursued by the HHI are an ideal complement to the work of the other ICT institutes in the FhG.
- It must be assumed that future Federal Government research funds will be mainly directed towards the ICT centres in the FhG. The HHI would therefore have a good chance of financial survival inside the FhG.
- Under the policy of reducing the financial deficit of the State of Berlin the institutional funding of the institute was cut. HHI has suffered a reduction in its annual budget by one million € in 1996 and the following years until today, despite of the fact that, in the meantime, it has very successfully passed two evaluations by the Science Council (Wissenschaftsrat) and two more by the Electrotechnical Industry's Association (ZVEI). The deficit in the State budget prevails – there has been an additional cut of 300 k€ in the 2001 annual budget in excess of the one million € mentioned above –, and it is uncertain whether the funding of the institute will recover during the next years.

The ICT centre in the FhG consists of the software oriented "Group of Information and Communication Technology" (VIK) and the hardware oriented "Microelectronics Group" (VµE). The HHI will be primarily a member of the VµE and a secondary member of the VIK. The Federal Government has provided an Integration Fund of € 69 million over three years, which aims to strengthen basic research and create synergies between the partner institutes. The HHI participates in seven projects in the Integration Fund.

In April 2001 Lucent Technologies and the HHI opened the joint laboratory "Tera Lab Nuremberg", in which, under the framework of a longer term collaboration, photonic high speed networks for the next generation will be developed. This is an area where Lucent Technologies and the HHI have already collaborated intensively in the past.

In July 2001 the HHI reached a collaborative research agreement with Fujitsu Lab Europe in the field of photonic networks and components, following earlier joint research projects.

The division of Photonics was certified as complying with the quality standard ISO 9001 in the year 2000. This certification was confirmed and renewed after the first control audit in July 2001.

In August 2001 the whole division of Electronic Imaging Technology at the HHI, together with its industrial partners, participated in the Internationale Funkausstellung Berlin (IFA), the international exhibition of consumer electronics. The presentations were very successful and excited much interest among many new companies and political institutions.

Following ten years of collaboration with Alcatel in several national and European programs, the HHI became a member of the global Alcatel Research Partner Project in December 2001, a project which started in

October 2001. Under this agreement the HHI has started four research projects in the area of photonic networks and components.

During the past years ten spin-off companies have been created from the HHI. Two of those, u^2t Innovative Optoelectronic Components and LKF Advanced Optics have merged to become u^2t Photonics GmbH. The company Vision Pearls Berlin did not survive the difficult year 2001. The remaining eight spin-offs counted altogether 300 employees in January 2002.

Over the last two years the HHI has established close links with the start-up companies MergeOptics GmbH, QDI Germany GmbH and u^2t Photonics GmbH, the work of which is closely related to the research and development activities of the HHI. These companies develop and produce high end components for photonic networks in close cooperation with the HHI, which also provides support in R & D as well as in prototyping and small-scale wafer and chip supply. In addition, through medium term agreements, the companies are granted access to the wafer technology and the measurement equipment of the HHI, which greatly facilitates their establishment and growth during the difficult first phase. The three companies are planning to increase their staff to 300 altogether by the year 2003. Thanks to the close ties between research and industry, Berlin has become the leading German centre of competency in the field of photonic semiconductor components for the Internet of the future.

In November 2001 the KomNet project was presented at a press conference at the HHI. KomNet was started by the Federal Ministry of Education and Research (BMBF) in May 1998 as a joint project between German industry and research institutes, with the aim of catching up with America in the field of Internet infrastructure development. The program, which ends in April 2002, has funding of € 42,4 million from government plus € 34,8 million from industry. The most significant testbed in the world for Internet technologies has been set up by KomNet. According to the industrial partners, KomNet has made an important contribution towards the leading international position which the German industry has now reached. The HHI has contributed a number of projects to KomNet, and also manages the System Integration Office.

The still young Department of Broadband Mobile Communication Networks is now firmly established in many national and European framework programs. Cooperation in the field of space-time signal processing with Stanford University, the Massachusetts Institute of Technology and the University of Illinois at Urbana-Champaign was further developed, and in the meantime several scientists from these institutions have worked at the HHI during longer research visits.

A breakthrough was achieved in the area of space-time signal processing. Base-station antenna arrays have the potential to drastically increase the spectral efficiency of wireless multi-user systems without increasing the complexity of the hand-held terminals. The HHI has developed a novel and computationally efficient optimisation scheme that minimizes the total transmission power while maintaining the individual link qualities. It can also be used to test the feasibility of a given scenario, and will thus prove useful for future real-time applications in which the sharing of resources must be optimised along with the dynamic channel management.

A historic partnership between ISO/IEC and the ITU was established at the meetings in December 2001 in Pattaya (Thailand) of the ISO/IEC MPEG (Moving Pictures Experts Group) and ITU-T VCEG (Video Coding Experts Group). A new Joint Video Team (JVT) was formed. This action reunites the powerful teams from the these organizations who designed the earlier MPEG-2 video and systems standards. The formation of the JVT follows the demonstration, in tests conducted by MPEG just prior to its July meeting, of significant advances in video compression technology by the VCEG H.26L project. The JVT project will take over the previous H.26L project of the ITU-T and will create a single interoperable solution for the next generation of standard video coding. The HHI made a significant contribution to this development by providing both the MPEG-4 reference codec and the H.26L codec. These developments were supervised by Thomas Wiegand, head of the Image Communication Group in the Image Processing Department of the HHI, who was also appointed as one of the two co-chairmen of the JVT.

Holger Boche, head of the Department of Mobile Broadband Communication Networks, has accepted the chair for Mobile Communications in the Faculty of Electrical Engineering at the Technische Universität Berlin. He will continue in his position at the HHI, thereby greatly benefiting the cooperation between the two institutions.

Thomas Sikora, head of the Department of Interactive Media – Human Factors, has accepted the offer of the chair of Communication Systems at the Faculty of Electrical Engineering of the Technische Universität Berlin (successor to Prof. Noll).

Ch. Fehn, P. Kauff, O. Schreer and R. Schäfer, members of the Department of Image Processing, were honoured in 2001 with the International Broadcasting Convention (IBC) President's Award for the best technical paper, entitled "Interactive virtual view video for immersive TV applications".

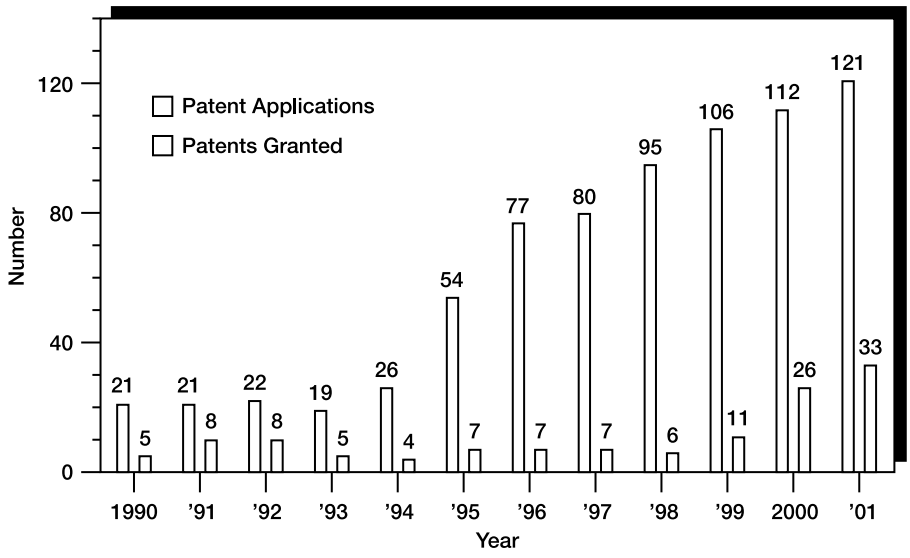
Over recent years several procedures have been developed at the HHI to evaluate the projects and departments of the Institute. We have now gained enough experience with these tools that it seemed appropriate to develop an integrated procedure. All projects in every department were evaluated with this internal control system (ICS) at the end of 2001. Based on these results, individual goals will be defined for all departments at the beginning of 2002. The goals for the departments during the coming years will be defined in such a way that, after a transition period of five years, the key parameters for the Institute will match those of the FhG. This has special significance for the required amount of external project funding. Appropriate strategies for the transition period are currently being developed in all departments and will be finalised soon.

At the end of the year 2001 the HHI had 272 employees, 19 more than the year before. The overall budget was € 29.6 million. The external funding was 52.7 %, an increase of 8.9 % over the previous year. External funding included 26.9 % from contracts with industry.

In the year 2001 the HHI was able to significantly increase its cooperation with industry, despite the economic recession. The HHI was very successful in competing for funding from the Integration Fund of the Federal Government, so that collaboration with many institutes of the FhG could be started. We wish to thank all members of the Institute for these achievements.

The leading theme in 2001 was, of course, the forthcoming integration of the HHI into the FhG. This important step, which is necessary for safeguarding the future of the Institute, was discussed at all levels of the Institute with fairness and objectivity, for which we express our respect and gratitude.

Berlin, January 2002
Clemens Baack, Wolfgang Grunow



Development of IP Portfolio (Inland)

Mission, Activities, Personnel and Financing

Information technology is one of the most important parts of the infrastructure of modern societies. The ever expanding global network will give virtually everybody access to immense information resources, which opens the door to the era of the knowledge based, or "information", society.

The expansion of communication networks has led to a huge market, currently worth $ 200 billion annually. Despite a market downturn of 10 – 20 % in the last year, when industrial capacities had to be readjusted, the user demand for broadband services is still growing, and the roadmaps for research and development in this field have had only minor revisions.

The paramount task in information technology is now the development of a seamless global network, which will consist of an optical Core Network, high capacity fibre optic Metro Networks, and Access Networks in which the end users are connected via fibre (or, as an intermediate solution, over copper wire), wireless or broadband mobile. The network must provide the bandwidth needed for the subscriber to access all existing and future communication and information services with high quality and low latency and, above all, low cost.

HHI has taken an internationally recognised role in several key areas of information technology: photonic networks, mobile broadband systems, and electronic imaging technology for multimedia. Its aim is both to expand the fundamentals in these areas and to develop new applications in close partnership with the industry.

In the research area of **Photonic Networks**, the ground is being laid for Terabit/s core and regional backbone networks by our work on optical time-division (OTDM) and wavelength-division (WDM) multiplex techniques, methods for all-optical signal regeneration, and ultra high speed fibre transmission experiments. For metro and access networks, dynamically flexible architectures with optical switching in conjunction with WDM techniques are also under investigation. Network management and protocol adaptation play an increasing role in seamless networks. Fibre to the home has again become an active research area, while customer in-house networks with a fibre optic infrastructure and wireless access require extremely cost-efficient solutions.

Our research work on photonic devices focuses on the next generation metro and core networks. Key components under development are semiconductor lasers for direct 10 GHz modulation in the future Ethernet; lasers for WDM networks; picosecond pulse laser sources, fast modulators and demultiplexer switches for OTDM networks; laser-based devices for optical 3R regenerators; and broadband receiver front ends for 80 Gb/s and beyond.

Optical crossconnects are becoming an important alternative to electronic switches for handling the multi-Terabit/s data throughput at network nodes. Wavelength converters based on semiconductor optical amplifiers have an important function in this application. Another group of components are planar waveguide devices for the passive optical network using the SiO_2/Si material system and optical polymers. Photonic bandgap structures are an advanced concept for optical elements and circuits, with great potential for realising ultracompact passive and active devices in future photonic networks.

Mobile communication is at present still limited to narrowband applications, in contrast to communication on the wired network. Because mobile networks, as an extension of the fixed network or as (ad-hoc) clusters, are continually increasing in both performance and penetration, there is a growing need for broadband mobile connections. The challenge for research is to develop suitable system concepts and techniques for broadband mobile systems. To do this we must reconsider the fundamentals of information and signal theory and show the feasibility of the new basic concepts in a demonstrator. This involves considerable effort to improve coding schemes and algorithms, to establish new technical principles, such as smart antenna systems for multiple-input multiple-output (MIMO) and space-division multiplexing systems, and to drive the development of the standards. The HHI pursues these topics with projects in the area of **Mobile Broadband Systems**.

Data compression is needed to use the network capacity economically, especially for high-rate video services. It is necessary to continue research in this area and to develop compression methods with not only improved performance, but also with new functionalities, especially for interactive applications. Furthermore, efficient network solutions using media codecs is of crucial importance due to their susceptibility to

transmission errors, especially for 3rd and 4th generation mobile networks.

Tele-Immersion is becoming increasingly important. Therefore new methods for 3D image processing, 3D displays and man-machine interaction must be developed. The goal is to enable the user to navigate and communicate in real and virtual worlds, and to use immersive services and applications over networks. The development of next generation information systems, which will enable the user to efficiently archive, search and retrieve data, is becoming increasingly important. Intelligent and user-adaptive systems will be needed to make it easy for the user to identify and access visual information, both natural and synthetic. It is important to pursue research on various aspects of usability engineering to develop applications and services that are user-oriented and user-friendly. The HHI is working on these tasks in the area of **Electronic Imaging Technology for Multimedia**.

At the end of the reporting year, the institute had 272 employees, 153 of whom were scientific staff and 119 technical and administrative staff. Of these, 121 positions were in the research area Photonic Networks, 80 in the research area Electronic Imaging Technology for Multimedia, 22 in the research area Mobile Broadband Systems, and 50 in central areas such as management, planning, administration and workshops. At the end of the year there were also four postgraduate doctoral students, eight persons in training, 92 student assistants and three guest scientists working at the HHI.

At the end of the year 2001 the overall budget was € 29.6 million. The external funding was 52.7 % which included 26.9 % from contracts with industry. Cooperation agreements were concluded with the leading IT companies. An outstanding event was the opening of the Joint Terabit Lab together with Lucent Technologies Germany in Nuremberg, where joint experiments on ultra high bitrate transmission are performed. Equally important is the new membership of HHI in the Alcatel Research Partnership Program, under which advanced research projects in all-optical signal processing, ultra-high bitrate transmission, semiconductor materials technology, and optical polymer devices have been started. A highlight of the joint national project KomNet (sponsored by BMBF and coordinated by HHI) was on 21 November, when the 1000 km link from Stuttgart to the Berlin metro ring network was switched on. The KomNet pilot system now carries data rates of up to 1.2 Terabit/s (32 channels at 40 Gb/s).

HHI has also engaged in strategic partnerships with innovative SMEs working on photonic components. These companies run collaborative R & D projects in the areas of high end components for optical telecommunication networks, such as fast lasers, WDM sources, modulators, and detector front ends. They also carry out system development and system testbed evaluation. HHI also serves these partners as a chip and wafer source for prototype series of new devices, thereby creating the opportunity for flexible and fast introduction to the market. Through these initiatives HHI has participated in creating some 100 highly skilled working positions in the Berlin area. Many of these collaborations with innovative SMEs are embedded in regional research framework programs supported by the Senate of Berlin.

We have continued our policy of increasing public relations and marketing activities, including presentations of our research activities at the technical exhibitions of the major conferences (OFC, ECOC) and at prominent trade fairs (CeBIT, Hannover Messe, Internationale Funkausstellung, etc.).

Last but not least, services in the areas of testing and measurements, feasibility studies, design work, e-beam mask plate manufacturing, and others, have contributed to our industrial relations.

HHI has further developed its quality management system to give increased customer orientation, and ISO 9001 was recertified in July.

Corporate Bodies

The corporate bodies of the HHI are the General Meeting, the Supervisory Board, the Managing Directors and the Scientific-Technical Committee.

Members of the **Supervisory Board** for this report period are:

Prof. Dr. G. Litfin, (chair), LINOS AG, Göttingen
MinDirig Dr. K. Rupf, (1st vice-chair), Bundesministerium für Bildung und Forschung, Bonn
ORR Dr. B. Colditz, (2nd vice-chair), Senatsverwaltung für Wissenschaft, Forschung und Kultur, Berlin (till Sept. 2001)
ORR B. D. Lietzau, (2nd vice-chair), Senatsverwaltung für Wissenschaft, Forschung und Kultur, Berlin (from Sept. 2001)
M. Ferstl, HHI, Berlin
Prof. Dr. P. Noll, Technische Universität Berlin
MinR W.-P. Ottenbreit, Deutsche Telekom AG, Bonn
RD K. Trantow, Senatsverwaltung für Finanzen, Berlin
Dr. H. Venghaus, HHI, Berlin
MinDirig M. Cronenberg (guest), Bundesministerium für Wirtschaft und Technologie, Berlin

The **Scientific-Technical Committee** is comprised of heads of departments and an equal number of elected members from the Institute, and advises the Supervisory Board and the Managing Directors on all important scientific and technical matters.
Further, the HHI has appointed a **Scientific Advisory Committee** of experts from industry, the Deutsche Telekom AG and the academic sector. Members and permanent guests of the Scientific Advisory Committee for this report period are:

Prof. Dr. J. Eberspächer, (chair), Technische Universität München
Dr. R. Fechner, Lucent Technologies Network Systems GmbH, Nürnberg
Prof. Dr. G. Fettweis, Technische Universität Dresden
Dr. H.-J. Grallert, Marconi Communications ONDATA, Backnang
Dr. R. Gossink, Philips GmbH, Aachen
Prof. Dr. W. Klimek, Deutsches Zentrum für Luft- und Raumfahrt e.V., Köln
Prof. Dr. P. Leuthold, Eidgenössische Technische Hochschule Zürich
Dr. M. Rocks, T-Nova Deutsche Telekom, Berlin
Dr. G. Ruopp, Marconi Communications GmbH, Backnang
Dr. B. Schwaderer, Tesat-Spacecom GmbH & Co. KG, Backnang
Prof. Dr. G. Siegle, Robert-Bosch-GmbH, Bonn
Dr. E. Zielinski, Alcatel SEL AG, Stuttgart

Organisation and Contact Persons

Directors

Prof. Dr. Clemens Baack	+49-30-31 002-200	baack@hhi.de
Dr. Wolfgang Grunow	+49-30-31 002-300	grunow@hhi.de

Departments

Optical Networks	Dipl.-Ing. Godehard Walf	+49-30-31 002-455	walf@hhi.de
Optical Signal Processing	Dr. Hans-Peter Nolting	+49-30-31 002-427	nolting@hhi.de
Broadband Mobile Communication Networks	Prof. Dr. Dr. Holger Boche	+49-30-31 002-540	boche@hhi.de
Materials Technology	Dr. Norbert Grote	+49-30-31 002-431	grote@hhi.de
Micro Fabrication Technology	Dr. Udo Niggebrügge	+49-30-31 002-550	niggebruegge @hhi.de
Integration Technology	Dr. Herbert Venghaus	+49-30-31 002-555	venghaus@hhi.de
Image Processing	Dr. Ralf Schäfer	+49-30-31 002-560	schaefer@hhi.de
Interactive Media – Human Factors	Prof. Dr. Thomas Sikora	+49-30-31 002-210	sikora@hhi.de

Central Services

Administration	Dipl.-Ing. Hartmut Mrowka	+49-30-31 002-310	mrowka@hhi.de
Planning + Marketing Photonics Coordination	Dr. Walter Döldissen	+49-30-31 002-253	doeldissen@hhi.de

R & D FIELDS

Photonic Networks

Topics and Results

Data transmission traffic is now growing at rates of 100 to 200 % per year. Telephone traffic, which is expected to grow at a rate of only 5 % per year, will soon be only a minor part of the total traffic. Worldwide telecommunication is therefore experiencing an explosive increase in the demand for transmission capacity. The main driving force behind this development is the Internet, which will evolve over the next few years into a Broadband Internet with an even higher demand for bandwidth. The Internet will be the backbone of the future information society and the main driving force of commerce and business.

Apart from microelectronics, the foundation for this development is optical fibre communication, which utilises photonic networks. The enormous capacity of an optical fibre enables the design and construction of high-capacity communication networks. Multiplexing techniques such as optical wavelength-division multiplexing (WDM) and optical time-division multiplexing (OTDM) will be further developed to exploit the large bandwidths of optical fibres. Moreover, in a photonic network the data are not only transmitted over the optical pathway, but they are also routed optically. Thus, the photonic network will be service-independent, offering high capacity pathways for all current and future services.

These developments will also increasingly affect the customer networks, i.e. the communication networks located in the premises of private or commercial users. As the information must be transmitted to the user's terminals, the customer network must link these multimedia terminals with the broadband Internet. The prognoses for the year 2010 are data rates of 150 Mbit/s for private and 1 Gbit/s for professional end terminal users.

Technologies for the future Broadband Internet are being developed and tested in 17 R & D projects under the framework of the German Federal Ministry of Education and Research (BMBF) funding initiative KomNet – Innovative Communications Networks for the Knowledge-Based Society. As well as theoretical work and experiments at the various laboratory sites, an experimental DWDM communication network connecting the cities of Berlin, Darmstadt, Mannheim and Stuttgart has been implemented. Initial segments of this testbed have already been set up by the individual project teams and have been put into operation. This network serves as the national-scale infrastructure to assess and to field-trial optical networking technologies, network elements, protocols and subscriber line approaches for the Next Generation Internet.

The HHI contributes to the KomNet projects through several subcontracts with the German telecommunication industry, including work on the design and simulation of optical networks, a loop testbed for WDM network elements, ultra-high-speed transmission using time-division multiplexing, 40 Gbit/s photodetectors, 40 Gbit/s receivers, and transceiver photonic integrated circuits. The HHI Systems Integration Office is also responsible for coordinating the network construction and the field trials.

The R & D Program KomNet will be finished in April 2002. The BMBF has now announced a new Program called MultiTeraNet, in which the HHI is also involved with many proposals.

The HHI is a partner in the project "Optical Technologies in Motion for the IST Program" (OPTIMIST). This project aims to facilitate concerted action in the general area of photonics across the whole of the European R&D program IST (Information Society Technologies). In particular it will encourage important synergies and interchanges, for example between systems projects and components projects, and improve awareness between industry and academia of new ideas and the results of longer-term research in the area of photonic technologies. These objectives will be achieved by organising topical workshops and meetings and a range of other dissemination activities.

The main objective of photonic research at the HHI is to make substantial contributions to the development of photonic networks. The following main areas are being addressed:

- Development of network concepts for photonic core, access and customer networks
- Investigation of the potential of optical multiplexing techniques such as OFDM and OTDM. The optimum combination of these techniques is of paramount importance.
- Determination of the limits of optical trans-

parency, i.e. the estimation of the transparency path lengths in photonic networks
- Determination of the requirements of the network concepts and photonic components, including the transmission lines and routing subsystems
- Investigations into the supervision (operation, administration and maintenance – OAM) and control (telecommunication management network – TMN) of photonic networks
- Investigation of functional linking methods between the physical and protocol layers
- Investigation of protocols for IP over WDM networks
- Development of methods and devices for all-optical signal processing for ultra high speed packet routing, signal monitoring and control
- Development and fabrication of photonic components and subsystems

The overall research area of photonic networks is divided into the two specialist areas Core Network and Access and Customer Network.

Core Network

Work in this research area concentrates on dense wavelength-division multiplexing (DWDM) and high bitrate time-division multiplexing (TDM) techniques, optical cross-connects, and optically transparent networks. Multiplexing and demultiplexing may be performed either electrically (ETDM) or optically (OTDM) in high bitrate TDM. The generation, modulation, detection and synchronization of the optical signals are important issues being studied. The effects of the photonic components and of fibre nonlinearities and dispersion on the quality of the optical signals are also under investigation.

Optical time division multiplexing (OTDM): The optical time division multiplexing (OTDM) work includes the investigation and realization of optical subsystems, and also transmission experiments at bitrates as high as 160 Gbit/s. An OTDM transmission system comprises several components and subsystems, as follows. On the transmitter side an optical pulse source generates a pulse train with a repetition frequency at the base rate, which in our case is 40 GHz, the highest electronic data rate available at present. This optical pulse train is coupled into four optical branches, in which the 40 Gbit/s electrical signals are modulated onto the optical pulse streams. These four optical signals are bit-interleaved by a delay multiplexer to generate a 160 Gbit/s bit-stream, which is transmitted via mono-mode fibres from various suppliers. At the receiver side, an optical demultiplexer separates the four base signals for subsequent electronic detection and processing. The demultiplexer must be very fast for bit-wise switching. The RZ data source was realized by a mode-locked laser. This data source has been demonstrated in 160 Gbit/s transmission experiments over unrepeatered (no optical amplifiers in the transmission line) transmission spans of up to 160 km of standard fibre. To compensate for fibre dispersion, we applied passive dispersion compensation using dispersion-compensating fibre.

We reported the first 160 Gbit/s OTDM system, which used optical demultiplexing to the base data rate of 40 Gbit/s, electrical signal processing at 40 Gbit/s, and transmission over standard single-mode fibre (SMF). This is the first demonstration of the next generation OTDM systems, which will use optical demultiplexing to the highest electrical processing speed available.

In-service quality monitoring of high bitrate optical transmission systems working at 160 Gbit/s has been achieved at the full line rate by using optical sampling systems. These systems provide the picosecond timing resolution needed to observe eye diagrams at this speed. Key devices are the clock recovery device and the fast switch for sampling. The clock recovery circuit contains an optical phase locked loop (PLL) in which the ultra-fast optical mixer is realised by a semiconductor laser amplifier in a loop mirror (SLALOM). The sampling gate is a nonlinear optical loop mirror (NOLM) containing 320 m of highly nonlinear fibre (HNLF, (λ_0 = 1547 nm).

Monolihically integrated picosecond pulse source: One of HHI´s central activities is the development of components and subsystems for OTDM/WDM systems for Tbit/s capacity networks. One of the key components is an optical picosecond pulse source. After several years of experience in setting up hybrid modules, HHI has started the development of a monolithically integrated device at a repetition rate of 40 GHz. Major challenges are to guarantee sufficiently low timing jitter and sufficiently high stability for use in 160 GHz OTDM systems. The opto-elec-

tronic integrated circuit (OEIC) architecture will include a biased saturable absorber and a gain-tunable and phase-tunable distributed Bragg reflector (DBR) within a cavity length of about 1.1 mm. The theoretical investigations and experimental analysis of the sub-elements have now lead to an OEIC fabrication process.

Monolithically integrated nonlinear interferometer switches: We have fabricated and investigated nonlinear Mach-Zehnder interferometers for use as demultiplexers. These use optical semiconductor amplifiers (SOAs) as nonlinear elements in the interferometer arms. With these all-optical switches, error-free demultiplexing from 160 to 10 Gbit/s with arbitrary choice of the switched channel was achieved in system experiments.

Further investigations were focussed on a different switching architecture, in which the working wavelength of the integrated SOA is 1500 nm while the data wavelength is 1550 nm. This is called the "band gap shifted" (GS) switching scheme. Its advantages are better linearity, enhanced extinction ratio and greater phase shift efficiency.

In cooperation with an industrial partner, we are developing a specially designed all-optical wavelength converter for 10 and 40 Gbit/s signals.

All-optical signal regeneration: Scalable networks need full "3R" (re-amplification, re-shaping, re-timing) signal regeneration. Components and methods for this function are under development. Optical clock recovery is performed using self-pulsating DFB feedback lasers. These three-section devices are controlled by three dc currents which switch the self-pulsation on and off and tune its frequency. Very large (two octave) tuning ranges and frequencies of more than 80 GHz have now been achieved using the new PhaseCom architecture based on a tandem DFB laser structure. The self-pulsation frequency synchronizes to the optically injected data signals, and thus realizes all-optical clock recovery.

In cooperation with Alcatel, a full 3R regenerator has been assembled using the self-pulsating laser for 40 GHz clock recovery and a synchronous modulation/soliton compression scheme for regeneration. This regenerator was tested at 40 Gb/s in loop experiments, with the loop comprising 160 km of dispersion-managed fibre and several EDFAs. The eye diagrams and the bit error rate (BER) were measured after 65 laps, corresponding to transmission over 10,000 km. The eyes were clearly open, and the BER was below 10^{-9}. Error-free transmission of 40 Gb/s signals over 10,000 km demonstrates that the all-optical 3R regenerator is very effective at suppressing the accumulation of noise and jitter.

To improve the yield of chirp-free, low jitter and high extinction ratio self-pulsating lasers, the influence of internal reflections has been investigated. Automatic characterization of multi-section lasers has also been introduced.

High-speed modulators: 40 Gbit/s optical modulators are key components for next-generation optical communication systems. $LiNbO_3$ modulators for this task are commercially available, but require relatively large RF driving voltages (> 6 V), and as a consequence very expensive driving electronics.

GaAs devices are more favourable in this respect, but even better performance and lower driving voltages are expected from InP-based modulators. The Mach-Zehnder modulator structure we developed is based on a travelling wave electrode design to ensure proper high speed characteristics. It is much smaller (< 3 mm^2) and needs less driving voltage (V_{PP} ~ 2V) than comparable devices made with GaAs or lithium niobate. This inherently low driving voltage is one of the key issues for future transmission rates of 80 Gbit/s and more.

High speed photodetectors and receivers: Fast photodetectors for the reception of high bitrate data streams at 1.55 µm wavelength have been developed under the framework of the KomNet project. These photodetectors were required to convert large optical powers with effective noise suppression. To achieve this, two waveguide-fed PIN photodiodes in a differential configuration were monolithically integrated, together with a spot-size converter at the optical input port, an optical 3 dB splitter, and biasing circuitry. Packaged as modules, the twin photodiodes had highly symmetrical output behaviour and a 3 dB bandwidth of 45 GHz. In system experiments and field trials, performed by an industrial partner, a differential polarization-dependent loss of only 0.34 dB was obtained, which is a 3 dB improvement of the optical signal-to-noise ratio compared to single-ended detector schemes. Data transmission at 43 Gbit/s with forward error correction (FEC) was successful.

Optical receiver front ends, monolithically integrated on InP, for high speed TDM transmission systems are also being developed as a part of the KomNet project. In addition to a waveguide-fed PIN photodiode with a spot-size converter, they also contain a monolithic microwave integrated circuit (MMIC) -like electrical preamplifier using high electron mobility transistors (HEMTs). Further improvement of device design, material properties and processing technology increased the 3 dB bandwidth to 50 GHz, as measured in completely assembled modules, at the same time maintaining the conversion gain (larger than 1 A/W) and the flat transfer characteristic. With a newly developed amplifier stage of cascode type using eight HEMTs, a conversion gain of 1.7 A/W was achieved. The receiver modules proved able to transmit a TDM signal with FEC at 43 Gbit/s during in-system experiments carried out by an industrial partner.

Ultra-fast switching devices: Following prognoses that an OTDM transmission bitrate of 1 Tbit/s may be achieved around 2010, the search for photonic materials with less than 1 ps switching capability is a key task. Hence the investigations into InGaAs/InAlAs structures grown at low-temperature were continued. An optical pulse train response with a characteristic time constant of the order of 250 fs could be demonstrated. As an alternative approach, work has been commenced to exploit ultrafast intersubband transitions in Sb-based quantum well structures.

WDM system testbed for novel network applications: The HHI operates a powerful measurement system for the investigation of various aspects of future DWDM networks. WDM systems with up to 16 wavelength channels, each up to 10 Gb/s, can be tested. This is being extended to 40 Gbit/s channel rates.

Long distances are simulated using multiple round trips in a WDM loop testbed. Multiple round trips correspond well with the ITU-T proposals to build networks with identical sections. The optical transmission sections (OTSs) include transmission fibres, optical amplifiers, and means for chromatic dispersion compensation. The transmission fibre for the 10 Gb/s channels is 80 km of standard SMF, and is compensated for dispersion using dispersion compensating fibers (DCFs).

The reason for testing long distances is to find the optimum configuration and parameters for dispersion management of so-called normalized sections when a large number of OTSs is cascaded. Such normalized sections are being investigated under a contract with a network operator. Different types of non-zero dispersion shifted fiber (NZ-DSF) sections are being tested. Optimization with respect to dispersion compensation must allow for the complex interplay between fibre nonlinearities and local signal dispersion. Various configurations, with pre-compensation, post-compensation or symmetrical compensation, have been tested with both NRZ and RZ signals and with ASK and DPSK modulation formats. The outcome was a series of charts showing the maximum transmission distances and the corresponding tolerances for the compensation ratio (CR) and the channel power levels. A maximum distance of 4000 km over standard fibres was achieved with NRZ signals, symmetrical compensation of the chromatic dispersion, and a CR of 99 %.

In consideration of future switched optical WDM networks with varying numbers of channels, the crosstalk penalty due to cross phase modulation (XPM) was measured in a 16 channel 10 Gb/s ASK NRZ long distance transmission system with 100 GHz channel spacing. Up to 3200 km the maximum XPM crosstalk penalty was below 2.5 dB, compared with single channel transmission. This result emphasizes the benefits of standard SMF systems for future flexible and switched WDM networks.

All tests and measurements performed in the WDM testbed are accompanied by numerical simulations. The agreement between measurements and simulations gives confidence in the correctness of both the measurement procedure and the numerical models.

Distributed Raman amplification: Distributed Raman amplification uses the transmission fibre as a gain medium and promises optical links with virtually zero attenuation over large wavelength ranges. Optimum pump configurations are being investigated for possible replacement of the standard erbium-doped fibre amplifiers in ring networks. A maximum distance of 4000 km was achieved with pure Raman amplification. A novel emergency switching system will be implemented to protect eyes from the high pump power levels if the fibre breaks.

Channel identification and performance monitoring: A problem not solved so far is channel identification and performance control in a transparent WDM network. This is most important in switched WDM networks. Novel control modulation techniques are under test that allow simultaneous identification and performance control. Two concepts with a combination of a 50 Mb/s control channel and a 10 Gb/s payload channel were found to have good quality correlation between the two channels, as required for performance control, and to give error-free transmission of both channels up to distances of 2500 km.

Design and analysis of WDM networks for IP: Optical networking is based on two complementary views, which are reflected in recent ITU-T recommendations and the current activities of the study groups. The functional view is mostly related to the management aspects, and the physical view to the transmission issues of the different topologies. The problem of designing transparent network domains is due to the analogue character of the channels. This complicates network planning because of the limited cascadability of the network elements and the difficulties of controlling the channels, especially in switched networks.

Ring networks are of great practical importance because of simple protection switching schemes. Various topologies for unidirectional and bidirectional rings with two and four fibres have been analysed for normal and protection-mode operation. The simulation results of a two-fibre ring with four add-drop nodes fully meshed through 40 Gb/s WDM channels using standard SMF indicates its suitability for metro rings up to 60 km perimeter without in-line amplifiers. A good approach to large meshed networks is seen to be a multiple connection of ring topologies using optical crossconnects.

Upgrading of such basic network topologies is planned towards switchable WDM networks and optical packet-switched networks at the IP level. This requires the application of wavelength-switchable transmitters, the implementation of optical crossconnects and the development of burst-mode receivers with fast clock recovery. Novel labelling techniques and routing measures will be simulated and tested in the WDM testbed.

Transinet – Innovative Transport Networks for the Broadband Internet: The objective of this joint project, which was begun in June 2000, is to develop new networking technologies to carry IP traffic over WDM optical networks in an efficient manner.

The main research areas for the next-generation optical Internet in the TransiNet project are new concepts for network and node architectures, the corresponding protocols, standards and technologies, traffic aggregation, scalability of WDM networks, Quality of Service (QoS), network management, resilience, and the interworking and integration of high-speed photonic and mobile communication systems.

At the HHI advanced optical subsystems such as WDM transmission, add-drop multiplexers, optical crossconnects and wavelength router/switches, together with their interworking with higher-layer protocols, mainly IP, are being investigated.

Parts of an IP-optimized air interface will be developed. The main research areas for wireless communications are new signal processing algorithms, estimation of the radio channel, resource allocation, and teletraffic techniques for the planning process.

Network and subsystem modelling: Methods for simulating optical components and signal propagation in an optical path are being developed, and are being checked by comparison with the experimental measurements. As well as the programs we have developed ourselves, we also use the commercially available program package "VPITransmissionMaker & VPIComponentMaker" from Virtual Photonics Inc. (a spin-off from HHI). With the transmission-line laser model it is possible to optimize photonic components and subsystems, such as the self pulsating laser and the nonlinear Mach-Zehnder Interferometer (used as a very fast optical gate), which can be connected to an all-optical circuit for 3R regeneration. The work towards high bitrate TDM and the combination of TDM and WDM technologies is also supported by analytical and numerical investigations, the main question being how to set up the transmission line to achieve optimum transmission capacity.

Access and Customer Network

Research and development activities in this area are concentrated on the use of WDM

techniques in the access network. Specifically, the goal is to develop and investigate system concepts and components for WDM applications in the access network.

Monolithically integrated laser component for optical transceivers: The bidirectional optical transceiver is a key component for the realisation of optical subscriber links. As the crucial crosstalk requirement of at least 50 dB optical crosstalk suppression, which was set by the Full Services Access Network (FSAN) group, is not met by small monolithically integrated transceivers, we focussed on the development of Fabry-Perot laser OEICs with integrated laser resonators and integrated 45° mirrors for the subassembly setup. The lasers include field transformers to reduce the numerical aperture. The full-wafer fabrication of the laser cavities by dry etching and of the 45° mirror by wet etching allows on-wafer testability of the OEICs and has the potential to reduce the module fabrication cost. The verification of the transceiver modules will be performed by the industrial partner who funded this development.

Laser devices: Multi-wavelength single mode sources are of great interest for future WDM networks. One prerequisite for obtaining high yield for laser arrays is to have a high single-mode yield for the individual devices. This topic has received particular attention during the last year. Different theoretical models suggested either to raise or to reduce the κL product of our DFB lasers. Finally an appropriate range of target values for κL, together with other design and technological parameters, was determined, and this enabled the fabrication of lasers and laser arrays with substantially enhanced single-mode yields.

Another activity is aimed at hybrid DBR lasers, which are comprised of an InP gain section and a fibre Bragg grating. Realizing the Bragg grating in a fibre (instead of InP) reduces the temperature-dependent variation of the emission wavelength of the hybrid laser by an order of magnitude. Low threshold current and high optical output hybrid lasers require efficient coupling between the InP chip and the fibre, and this in turn requires an InP chip with an integrated spot size transformer. Such devices have been developed and prototypes have been transferred to a company which will soon produce chips in larger volumes and commercialize the hybrid laser.

With the expansion of optical networks into the metropolitan and access areas, the demand for inexpensive laser sources with high performance will steadily increase. A modulation speed of 10 Gbit/s, uncooled operation up to 85° C, and a high optical laser-fibre coupling efficiency are of crucial importance. Various research activities were carried out in pursuit of these goals. Tapered laser diodes with a burried hetero (BH)-type structure and 10 Gbit/s modulation capability have been developed. To improve the high temperature performance, gain material based on InGaAlAs has been optimized and tested in ridge waveguide- (RW) -type lasers. Dry etching was also successfully applied to form the facets. Vertical cavity lasers are another approach to achieving low cost light sources. A design is being investigated for the 1.3 µm wavelength that uses oxidized Bragg mirrors and a GaInAsN active layer. Work on this demanding structure has concentrated on its technological problems.

Micro-ring filters: Miniaturisation of waveguide circuits is inherently connected with the implementation of highly confined waveguides, which opens the potential for realising optical micro-ring circuits. Integrated optical ring resonators are promising candidates for compact optical filters and wavelength multiplexers and demultiplexers. Their realisation in active semiconductor material could lead to “lossless” filter devices as well as novel laser components with outstanding performance. As ring resonators do not require facets or gratings for optical feedback, they are particularly suited for monolithic integration. We followed our strategy of learning from passive devices, then improving their performance by integrating semiconductor optical amplifiers (SOAs), and finally extending the functionality in all-active structures. Passive single and multiple ring filters as well as add/drop multiplexers could be demonstrated, including fine tuning of the filter response by integrated platinum heaters. First results on fabricated SOA integrated ring resonators and all-active resonators in the transmission and emission mode have been obtained.

WDM filter components: As well as arrayed waveguide gratings (AWG) and special components associated with them, additional waveguide components based on established silica technology have been developed, especially OTDM multiplexers and

beam forming networks for broadband mobile communications.

The beam forming network uses the interference between two neighbouring optical frequencies to generate an intermediate frequency in the 60 GHz range. These signals are split into 4 or 8 outputs, which are individually phase shifted to change the beam characteristic of a microwave antenna. Two different silica-based planar lightwave circuit (PLC) devices designed for optical phase control and amplitude control were implemented and assessed.

The AWG activities include a special AWG for passive optical networks. The idea is to overlay a broadcast wavelength onto WDM channels. Following previous work on such a component, this concept was successfully extended to bidirectional WDM transmission. Prototype devices with excellent performance were demonstrated.

Another important AWG activity was based on the use of polymer materials to form not only the optical waveguide but also the substrate. By properly adjusting the thermal expansion coefficient of the substrate, consisting of polymer materials developed by FhG-IZM, a novel scheme to achieve athermal behaviour, i.e. channel wavelength independent of temperature, was successfully developed.

Photonic crystals: Photonic crystals are exciting new materials in photonics, still in the stage of fundamental research. HHI has recently entered this area using silicon-on insulator (SOI) as the most promising material. So far, basic design work on waveguides and etching studies have been carried out.

Competencies

Investigation and development of architectures for photonic networks, development of planning guidelines, and studies of specific problems of photonic networks

Characterization and testing of optical networks and network components, including experiments on fibre loops, transmission experiments over large distances, and field trials

Development of high rate optical WDM systems (10 Gbit/s per channel) and the corresponding measurement methods

Investigation, design and development of optical WDM LANs/MANs, optical access networks and passive optical networks

Development of methods for the control and supervision of networks

Development, application and verification of simulation software for optical transport networks

Design and development of optical systems using heterodyning

Development of wavelength conversion methods for WDM systems

Investigation and development of high rate OTDM subsystems (40 to 160 Gbit/s and above), including multiplex/demultiplex and add/drop techniques

Development of methods for purely optical clock recovery and signal regeneration (2R and 3R) for bitrates of 10 to 160 Gbit/s

Development of methods for the control, maintenance and supervision of high rate OTDM subsystems

Development of methods for the generation of ultra-short optical pulses

Development of optical sampling methods for network monitoring

Optimization of methods of dispersion management

Design and development of optical frequency reference equipment

Design and fabrication of transponders and optical synchronous digital hierarchie (SDH) front ends

Development, fabrication and characterization of fibre optic components

Development, fabrication and characterization of methods and devices for polarization mode dispersion (PMD) compensation

Development, fabrication and characterization of opto-electrical components and photonic integrated circuits based on InP:
- Multi-wavelength laser arrays

- Optical amplifiers with spot-size transformers
- High-speed laser diodes
- Wavelength converters
- Demultiplexers and add/drop multiplexers for OTDM applications
- Components for optical clock recovery and signal regeneration (self-pulsating lasers)
- Integrated transceivers
- Fast waveguide-fed, high-power photodiodes with optical spot-size converters
- Differential mode photodetectors (twin photodiodes) with integrated spot-size converters
- High bitrate optical receiver front ends with integrated spot-size converters
- High-speed monolithic integrated pulse sources
- Optic/microwave converters

Development and fabrication of polymer-based devices (thermo-optic switches and switch matrices, AWGs)

Development and fabrication of planar waveguide components on SiO_2/Si

Development and fabrication of diffractive optical components

Modelling of photonic components, photonic subsystems and integrated circuits

Development, optimization and application of component technologies:
- Clean room laboratories (class 10/1000)
- Epitaxy (MOVPE, MBE) and characterization of InP-based semiconductor materials
- Secondary ion mass spectroscopy (SIMS)
- CAD/CAM of photolithography masks
- Electron beam lithography and optical lithography
- High resolution scanning electron microscopy
- Atomic force microscopy
- Dry etch processes (reactive ion etching, ion beam etching) with endpoint detection
- Rapid thermal processing
- Deposition of metal and dielectric layers (evaporation, sputtering, plasma deposition)
- Optical coatings
- Characterization and technology of optical polymer materials
- Chip mounting and connection techniques
- Fibre-chip coupling (single and multiple input/output ports)
- High-frequency packaging

Mobile Broadband Systems

Topics and Results

Mobile communication is rapidly growing and is now an important economic factor. It will grow even more and even faster with the imminent wireless internet access and the implementation of wireless LANs (WLANs). The HHI activities in mobile communication concentrate on improvements for systems of the third generation, such as UMTS/IMT2000, and on the design of WLAN and fourth generation systems.

Due to the extreme costs of spectral bandwidth, which became obvious at the UMTS licence auctions in Great Britain and Germany, improvement of the spectral efficiency of these systems is essential to increase the overall system capacity and to give an acceptable return on investment within reasonable time spans. Therefore smart antenna systems and multi-user detection principles to improve the spectral efficiency of UMTS are being investigated at the Heinrich-Hertz-Institut. Strategies are also being developed that allow for the strongly asymmetric traffic of future services such as IP over wireless.

New approaches are being investigated for efficient resource allocation in future mobile systems, including consideration of the characteristics of new services. In particular, fundamental principles for an IP-optimized mobile communication system are being investigated. Also, new multi-user receivers are being conceived and signal processing algorithms are being optimized. In addition, work is proceeding on the integration of mobile and photonic networks. New concepts for fourth generation systems are being developed for multiple access control, interference reduction and network planning. These methods are based on the application of optimization techniques to code division multiple access (CDMA) systems, orthogonal frequency division multiplex (OFDM) systems, and non-orthogonal multiple carrier systems.

Future cellular systems must be able to support high-rate multimedia services even with high user densities. This challenging goal can be attained by using antenna arrays at the base station. One way to make efficient use of the spatial diversity provided by the array is to steer the receive and transmit beams towards the desired users, with the radiation pattern periodically updated depending on the instantaneous channel characteristics. In this way considerable carrier-to-interference gains can be achieved, which may be directly traded for improved quality of service, greater user density or greater data rate. The HHI carries out theoretical and experimental research in the field of beamforming and applies this knowledge to the design of new algorithms for both up-link and down-link space-time processing.

Compared with the conventional matched filter receiver, a multi-user receiver that utilizes the structure of the multi-access interference can substantially increase the spectral efficiency of CDMA using direct-sequence spread-spectrum methods. An important observation is that both the performance and complexity of such receivers strongly depend on the choice of the spreading sequences. Moreover, if signals are transmitted via a time-variant multipath channel, careful design of the training sequences is required to ensure a small channel estimation error. Hence we have been concerned with the design and allocation of spreading and training sequences so as to achieve the best performance of CDMA-based mobile communication systems.

The antenna arrays and the related radio frequency devices must be calibrated for certain smart antenna applications. In particular, highly accurate antenna calibration is required for high resolution direction-of-arrival estimation algorithms, for null-steering beamforming and for optimal down-link beamforming at the cellular base stations. At the same time, in commercial mobile communication systems the overhead in terms of radio resources and system components that is required for calibration must be as low as possible. Therefore we have developed optimized robust calibration schemes. A detailed analysis of the physical device properties has resulted in a highly accurate calibration model. Using this model we successfully demonstrated a nullsteering beamforming application with an experimental array antenna system in a laboratory environment. For commercial system applications we are developing calibration algorithms that are based on efficient mathematical and computational methods.

There is a new class of smart multi-element antenna (MEA) systems that are promising candidates for wireless mobile systems with very high spectral efficiencies and capacities. These are based on MEAs at both ends of the wireless link, with space-time encoding at the transmitter, simultaneous transmission of different data streams at the same carrier fre-

quency, and signal reconstruction at the receiver. Repeated estimation of the complex matrix channel elements is required for signal detection in the quasi-stationary flat Rayleigh fading environment. First sets of algorithms and hardware architectures for multiple-input multiple-output (MIMO) channel estimation and for signal recovery in different MEA systems have been investigated and compared with Lucent's VBLAST demonstrator. All systems have been designed to support high-speed real-time indoor WLAN applications.

If channel state information (CSI) is available at the transmitter, then it is possible to do signal processing before data transmission. In order to calculate the required transmit power, the probability density functions for the eigenvalues and inverse eigenvalues of Rayleigh and Rician MIMO channels have been investigated and analytic expressions for the moments of these distributions have been derived. Since the radio channel is reciprocal, CSI can be made available at the transmitter by taking it from the CSI used at the receiver for signal detection. Linear channel inversion (LCI) is a simple processing scheme using CSI at the transmitter. In the down-link, data are multiplied at the transmitter by the pseudo-inverse of the transposed channel matrix H^T, while slightly more complex processing is needed in the up-link. Like VBLAST, LCI offers significantly better performance than zero forcing. However, LCI needs less signal processing than VBLAST when the number of data streams is large.

The combination of OFDM and smart antennas (MIMO-OFDM) turns out to be a promising candidate for future fourth generation mobile systems, since it offers high spectral efficiency and low-complexity equalization in the most demanding wireless environments. The capacity of this system concept was investigated, starting with a physical description of the underlying broadband space-time channel, and gave very encouraging results. Channel estimation is crucial for exploiting the capacity, and highly efficient estimation schemes were proposed. The design of the space-frequency code is currently under investigation, to round out the complete system concept.

Smart antennas in the 60 GHz range will play an important role in future mobile communication systems at data rates of 155 Mbit/s. The generation and distribution of the microwave signals, and also beamforming, will be carried out using optical microwave technology, which allows the realisation of simple base stations in the picocellular network. The required microwave signals, with quartz stability and low phase noise, are generated using the optical heterodyne principle with modulation sideband injection locking. Beamforming is accomplished by a newly developed a SiO_2/Si-based beamforming network. The beamformer components and the beam steering algorithms will be tested in an experimental system, and first experiments have been successfully carried out. The RF properties at 60 GHz of the phase and amplitude sections of a 4-channel beamformer were measured using an antenna test setup with a 1 x 4 phased array antenna. Error-free 155 Mbit/s data transmission was achieved at various look directions of the antenna. This system presently uses the maximum-directivity beamforming algorithm.

Optical millimetre-wave techniques for beamforming array antennas are being investigated and specific components are being developed as part of the European OBANET project. This project is studying various coverage-area management strategies and the technologies required to optimise their performance. The scenarios of fixed and mobile broadband radio access in the 40 GHz band are both being considered. An important issue for beamforming and beam steering is the estimation of the direction of arrival. To investigate this problem, methods using pilot signals in a 40 GHz system are being implemented at HHI, and DSP is being used to evaluate them.

The beamforming and MIMO techniques currently being investigated lead to a drastic reduction of transmitter power, which greatly eases the electromagnetic interference problem. The reason for this is that the transmitter power with beamforming is concentrated in the strongest paths between the transmitter and receiver, which saves a considerable amount of RF power compared to nondirected emission. MIMO systems offer both diversity gain and multiplexing gain over single-input single-output (SISO) systems. These gains translate into drastically increased capacity, which can be used either to transmit more information without increased power or to save power at constant data rates.

Electronic Imaging Technology for Multimedia

Topics and Results

The R&D contributions of the HHI to this research area are in the domains of Image Processing and Interactive Multimedia Applications.

Image Processing

The HHI activities in image processing are concentrated on signal processing and coding for video services in various applications, on the design of VLSI components, and on system integration. A wide range of image formats, from very low resolution for narrowband video communication up to high resolution for multimedia services, are supported. Typical applications include VLBV (very low bitrate video) for multimedia communication at low bit rates over the Internet or mobile networks, interactive multimedia services, broadcast and communication services, and studio applications.

As far as hardware projects are concerned, the development of architectures for future multimedia terminals is the central activity, with the focus on key components for 3D graphics, compositing, MPEG encoding and decoding, and format conversion.

One emphasis is on the collaborative project Interoperability for Video Communication over Distributed Networks (INVINET), which is sponsored by the Federal Ministry of Education and Research (BMBF). The main aims of this project are the development of basic technologies for IP-based video communication, especially for mobile networks, and of interactive services over these networks, particularly those using virtual environments. Important topics are the new compression standard H.26L that is being developed in ITU-T, the development of an authoring tool based on MPEG-4 for the creation of 3D scenes, and a 3D compositor for MPEG-4.

• As a result of its work on H.26L coding, HHI submitted a proposal to the ITU-T for standardization, which has been accepted. The proposed scheme is a new and efficient method for context-based adaptive binary arithmetic coding (CABAC), which gives bitrate savings of up to 40 %.

• HHI has taken over the responsibility for the integration of the H.26L reference software.

• HHI has delivered two sets of test sequences for comparison tests organised by MPEG. One set has been encoded with an MPEG-4 Advanced Simple codec optimised for rate distortion, and the other with an H.26L codec, also optimised for rate distortion. Both codecs were developed at HHI and are the most efficient MPEG-4 and H.26L codecs known. Based on these tests, MPEG has selected H.26L as the best codec among seven proposals, and it will be used as the basis for the development of a new MPEG coding standard.

• The development of an MPEG-4 player containing a 3D compositor has been completed. This player was used to demonstrate a traffic information system based on MPEG-4 at IFA 2001.

The development and verification of technologies that are required for new functionalities in mobile multimedia and Internet systems is of crucial importance. Such functionalities have been identified in ISO-MPEG, and the MPEG-4 standard will be the basis for image and sound compression in future multimedia systems. These new functionalities, including content manipulation, content-based scalability and content-based access, are obtained with coding algorithms that are both very efficient and robust against transmission errors.

• Hardware architectures for a complete MPEG-4 mobile multimedia terminal , based on embedded processor cores and state-of-the-art memory technology, have been further developed, and MPEG-4 decoders have been ported to different platforms (Trimedia, ARM, TI).

• A video streaming application over WLAN has been implemented and was demonstrated at IFA 2001.

• A final version of an e-commerce system based on MPEG-4 software components has been developed, in cooperation with T-Nova and Blaxxun Interactive, for the IST project SoNG (Portals of Next Generation). The client part of this e-commerce system is Web-based and consists of a generic, application-unaware MPEG-4 compositor that can be embedded in an HTML page, along with application-specific Java code and MPEG-4 video encoder and decoder modules. The core of the application logic is implemented in downloadable Java code modules, which communicate with the MPEG-4 compositor using the standard compliant MPEG-J API. A content provider can update the content and logic of the e-commerce system by

changing BIFS, Java or JavaScript code on the HTML/MPEG-4 server. The video encoder and decoder facilities of the system allow customers to contact sales and support staff using audio or video communication. This system was demonstrated at IBC 2001.

Audio is an important feature of many MPEG-4 application projects. Due to its many refinements, MPEG-4 AAC (Advanced Audio Coding) is the most efficient audio compression technique known at present. This standard supports sampling rates from 8 kHz up to 96 kHz and provides audio of near CD quality at a very low bitrate (64 kb per channel). The AAC standard handles up to 48 channels in one bit stream, and is therefore suitable for any multichannel application. MPEG-4 AAC can be used in a wide range of applications such as home cinema, internet audio and hand-held players/recorders.

• Audio encoders and decoders based on the AAC standard have been further developed. The implementations on PCs and DSPs are compliant with the ISO/IEC 14496-3 AAC MAIN and LC (Low Complexity) profiles, and deliver very high audio quality, almost indistinguishable from the original PCM. The software version for PCs is able to encode 4 channels of audio data and decode up to 17 channels in real time. The ANSI-C implementation allows the algorithm to be transferred to other hardware platforms without extensive modifications. The TMS320 C6x DSP series from Texas Instruments has been chosen for the DSP implementation. These implementations were all exhibited at IFA 2001 and IBC 2001.

Image analysis and feature extraction are basic technologies for intelligent network assistance systems. They facilitate access to multimedia information over networks. Methods of processing for image analysis and classification are being developed for this purpose as part of the MPEG-7 standardization process. In addition, object-based and model-based methods are being investigated and further developed for the extraction of useful visual parameters for such systems. These techniques will enable the user to search for information among the increasingly overwhelming choice of programs that are available over hundreds of DVB channels and the Internet. To achieve this, the audio and video streams must be provided with standardized index information to enable search engines using MPEG-7 to browse for special features. The selection of a program with given content can then be either user controlled or event driven (e.g. a sports channel could be automatically switched on if a goal is scored in a football match).

• Several components for the MPEG-7 standard have been specified and basic descriptors for low-level signal-based features and all visual features (colour, texture, shape, motion) have been developed.

• HHI descriptors have been accepted as part of the MPEG-7 standard.

• Multimedia Description Schemes (Mid-Level Description of Multimedia Content) have been developed by HHI and contributions have been made to the official MPEG-7 Reference Software, to the definition of its binary syntax, and to the overall MPEG-7 system design.

Computer graphics and image processing technologies have reached a state that allows the development of novel multimedia applications and services. The new challenge in the field of television and multimedia applications is called immersive telepresence, in which users should feel that they are immersed in the scene. Large displays with high resolution are required. Two major applications are 3D video conferencing and immersive television. The increased resolution, in particular, requires new approaches in the whole image processing chain. Major contributions to 3D video processing have been made:

• For 3D video conferencing, the complete processing chain, including segmentation, disparity estimation, view combining, MPEG encoding and decoding, 3D warping and novel view synthesis, has been tested successfully using computer simulations under real-time conditions.

• The development of a DSP-based PCI board called VPS (VIRTUE Processor Station) has been finalised und is currently being tested under real operating conditions. It consists of a multi-processor board and an interface board, and supports flexible digital video input and output. The objective of the VPS is to assist real-time 3D video processing in a state-of-the-art PC. It has a standard PCI interface and offers flexibility of software implementation and scalability in terms of future extensions. It is the core of a prototype terminal for immersive 3D video conferencing.

• Two slightly different earlier versions of this device had already been made as part of the European IST project VIRTUE at Sony UK and of the BMBF project ITI at HHI. The VIRTUE

version was successfully demonstrated in December 2001 at the IST exhibition Event 2001 in Duesseldorf.

Immersive Television (ImTV) is currently gaining increased attention. The philosophy of ImTV is to deliver a combination of different depth cues, such as wide field-of-view imagery and head motion parallax or stereo vision, in order to evoke in watchers the sensations and emotions of being present at a live event. As a first step in the realization of this objective, a hardware system consisting of three fixed-view HD cameras (centre view and side panels) for capturing the live events has been developed. A home receiver unit is able to combine these images into a panoramic Ultra-High Definition (UHDTV) view. The UHDTV images are displayed using either flat or curved screen projection systems or a head-tracked, look-around head-mounted display (HMD) system.

The HMD feature is a further step of an evolutionary strategy towards a future ImTV service. The ultimate goal behind this strategy is a visionary TV system, called Interactive Virtual Viewpoint Video (IVVV), that allows the user to walk freely around in a natural video scene, as known from virtual reality applications. The following results have been achieved so far:

• A first prototype version of a UHDTV receiver, based on MPEG-2, was demonstrated at the IFA fair in Berlin in September 2001. Further extensions supporting the HMD option are in development and will be tested very soon.

• First extensions towards an IVVV system have been designed and investigated using computer simulations. This system extension is based on MPEG-4 and includes head-motion parallax viewing to stimulate depth perception. An IVVV-related contribution to the IBC conference in Amsterdam in September 2001 was honoured by the President's Award for Best Technical Paper.

• A concept of a hybrid MPEG-2/4 transmission system for the evolutionary introduction of scalable and backward-compatible IVVV systems into the existing DVB framework has been developed for future integration work.

The integration of video decoding, format conversion and graphics is one of the challenges in the design of future multimedia terminals. A multi-standard Display Unit for MPEG Applications (DUMA), consisting of highly integrated components, has been designed in the KOKON project. The system, which is based on FPGAs, DSPs and microcontrollers, combines video and graphics outputs from various decoder sources (MPEG-2 HDTV, MPEG-2 SDTV, MPEG-4) into one high-resolution video output. DUMA includes the main functions of the types of video output units that will become increasingly essential in future multimedia systems.

• Various components of a multi-standard display unit for MPEG-4 applications have been developed. This demonstrator will include the main functions of a display unit which combines the video and graphic signals from various sources (MPEG-2 decoder, MPEG-4 decoder, PC graphic system, etc.) into a high-resolution video output (HDTV). It will provide several interaction options. This interaction can be controlled by software running on an onboard RISC processor (StrongARM), which can also be used to decode various audio standards (AAC, CELP, MP3). In order to reduce the amount of hardware, an FPGA-based solution has been chosen. All functions are implemented in VHDL and can be used as modules in subsequent chip designs. The board has several standard interfaces for video (FBAS for TV, DVI), audio (I^2S) and control (EPP). This hardware unit allows verification under real-time conditions, and will also be used as an emulator for future ASIC developments.

Interactive Media – Human Factors

The HHI carries out R&D in the area of interactive multimedia services and new media, concentrating on user friendly multimedia applications, interaction technologies and multimedia terminals.

The focus of the work is on autostereoscopic display technologies, novel and trend-setting technologies for 3D desktop computers, the development of innovative 2D and 3D interaction techniques for man-machine communication, virtual telepresence and tele-immersion applications, methods for data search and data visualisation, and intelligent agent-based information management and user guidance. These main themes are extended by both fundamental and applied work in the area of usability engineering, with special emphasis on human factors constraints.

The autostereoscopic display developments concentrate on approaches that do not require the user to wear special glasses when viewing natural or computer generated 3D images or videos. Applications of this

technology are in the areas of 3D telephony and video conferencing, 3D TV, 3D multimedia desktop computing, 3D virtual worlds, telepresence, telework, telesupervision, vehicular technology, CAD/CAM, 3D computer games, medicine, and biology. The work in these areas includes the development of small to large flat panel autostereoscopic displays for one or more viewers, as well as large format front or back projection displays using either lenticular array screens or field lens technology. Prototypes of these developments were introduced to the public this year at the IFA 2001 (Internationale Funkausstellung) in Berlin and last year at many trade fairs and exhibitions.

• High resolution single-person autostereoscopic 15.1" and 20" flat panel displays ((2x512)x768 and (2x512)x1280, respectively) for use in the CAD/CAM area were developed. These do not require mechanical tracking of the lenticular screen – instead, the monitor is mounted on a mechanical tracking platform so that the image plane can track the user's head movements.

• An autostereoscopic 15.1" notebook display ((2x512)x768) for use in mobile applications was developed.

• High-resolution single-person autostereoscopic 20" flat panel displays (both (2x512)x768 and (2x512)x1280) for use in the CAD/CAM area were also developed. This particular technology consists of a 20" NEC display and a removable lens plate connected to the NEC device. IR head tracking measurements in combination with pixel switching technologies give the users tracking comfort when moving in front of the screen.

• A high-resolution autostereoscopic single-person display using field lens technology was developed for applications in video communication. In order to show figures in natural size for telepresence applications, the display integrates a collimation lens system to create a virtual image several metres behind the display surface. The display has outstanding resolution and brightness and minimal crosstalk.

• A large format 40" autostereoscopic back projection display with extremely high resolution ((2x1000)x750 pixels) was developed for applications in multimedia desktop computing. This monitor features mechanical tracking of the lenticular screen.

• A video-based head tracker was developed so that the HHI displays can be used without special glasses.

• A newly developed IR head tracker for the same purpose provides the same functionality at reduced cost and with reduced sensitivity to lighting conditions.

In recognition of the need to develop new concepts and technologies that point the way to the 3D desktop computer of the future, the work at the HHI concentrates on the vision of a computer with intelligent man-machine interfaces. To make operation easier for the user, prototypes of desktop computers were developed that present information in a clearly arranged and sufficient form using a 3D display and suitable 3D visualisation methods. The wishes of the user are anticipated by innovative multimodal interaction and agent technologies, thus enabling simple and intuitive operation in interactive applications.

An advanced prototype of an intelligent and 'seeing' 3D desktop computer that overcomes the disadvantages of the common windows desktops and allows novel forms of user interaction was implemented and shown publicly at various trade fairs and exhibitions.

• The development of a novel 3D visual operating system and suitable editors gives the desktop computer a simple and clearly arranged representation of multimedia information, together with simple means for the user to interact with it. In contrast to conventional windows-based desktops, the new operating system is object oriented and can layer information in the depth dimension.

• A 20" high-resolution autostereoscopic display that was developed in the HHI was used for the prototype of a 3D computer that allows the visualisation of multimedia objects arranged in the depth dimension. These objects are generated and managed by the 3D operating system. Because of the autostereoscopic representation, the user can see the objects and information stacked in depth layers, and can view them from different sides by moving his or her head (movement parallax).

• An improved video-based method of measuring the user's head movement and gaze direction that was developed at the HHI relieves the user of the need to wear either head markings or special glasses.

• A binocular camera-based hand tracking system was developed for novel man-machine interaction applications. This device is able to track hands or fingers in front of a screen in real time, so that the user can point to and interact with 3D objects projected us-

ing 3D displays in front of a screen. Based on software computer vision algorithms, this technology performs tracking in real time on general purpose PCs.

• An interface agent can recognise what the user is viewing and can then autonomously initiate appropriate actions (visually controlled graphics). In this way the representations of the displayed objects can be changed in a manner that is adapted to the user (e.g. the depth representation of the objects can be changed to model the depth-of-focus behaviour of the human visual system). Also, the user can initiate actions by means of gaze control.

• A prototype system for teleworking in 3D was developed and presented to the public at the IFA 2001 exhibition in Berlin. It allows teleworkers to jointly develop and manipulate 3D objects. The components of this system include an autostereoscopic 3D display, a visual 3D operating system, a camera that senses head and hand position, and a system to determine the gaze direction (for gaze-controlled interaction).

Research in the area of algorithms for 2D and 3D image processing was carried out in order to equip future generations of multimedia terminals and desktop computers with a large degree of intelligence and new forms of man-machine interaction. Applications are in the areas of 3D desktop computing, teleworking and telepresence. The work in this research area concentrates on user recognition, object recognition and tracking, 3D depth estimation, 3D intermediate view generation, and head and gaze tracking.

• A video-based head tracker was developed with the aim of presenting users of an autostereoscopic display with views of 3D images from various directions. The algorithm that was developed responds reliably to even the smallest changes of head position, even in difficult lighting conditions, and passes the measurements to a head tracking display. This algorithm works in real time and was implemented under IRIX on O2 and under Windows NT.

• The video-based head tracker was extended, using infrared techniques, so that it can also measure gaze direction. Gaze direction measurements are also being investigated for possible use as input variables for interactive purposes in future desktop computers (visually controlled graphics).

• A new work item dedicated to people sensing technologies was initiated in 2001. The purpose of this research effort is to equip systems and devices with the ability to detect people in front of devices or in their surroundings. Of particular interest is the identification of users, the sensing of their interactions with others, the sensing of their emotions or communication abilities, and the recognition of their gestures or general intentions.

Informal communication is an important aspect of human communication. This includes spontaneous and mostly confidential conversations, e.g. on the fringes of conferences, during coffee breaks or at other chance meetings. Since this form of communication has a positive significance for the individual worker as well as for the organization, means of providing technical support for informal communication among distributed work groups (for either telework or telecooperation) are being investigated. A questionnaire to potential users of telecooperation systems showed that informal communication in many areas connected with work is viewed as absolutely essential.

• To determine the essential features needed for telecooperation systems to support informal communication, various field studies were carried out using a chat system, a chat system extended by still images, and a virtual environment. The results showed that informal communication is possible with text-based communication systems, but that they should be augmented by indicators of the degree of communication readiness of potential communication partners.

• For telework applications, the telepresence of a work group was simulated using a virtual office environment generated by computer graphics. Each participant of the telework group, including his or her position and actions in space, was given a computer graphic representation (avatar). This concept appeared to be promising, especially for informal communication among teleworkers. It delivered a high degree of telepresence with a sufficient degree of privacy protection.

• A PreMon Awareness Monitor was developed that senses whether a teleworker is present in front of the monitor, and whether he or she is working or participating in oral communication. Speech and vision sensors are used in this monitor.

• In view of the increasing importance of mobile teleworkers, the PreMon Awareness visualization system was also adapted for use in mobile phones based on the WAP protocol.

Technology that allows users to search and navigate through large image data bases is

attracting increasing attention in research and development. Work was carried out in the context of the MPEG-7 standardization activities, with particular focus on adaptive and learning algorithms that are trained for the preferences of the particular user and that can search for images based on visual similarity measures. New philosophies and algorithms were developed for clustering and displaying image content based on human visual criteria.

- Human factors studies were initiated to understand how human viewers perceive and categorize information in images.
- New 3D visualization tools were developed that enable the user to navigate intuitively through an image database.
- A cognitive map of the database content, similar to a city street map, allows the user to navigate through an image database using a coarse-to-fine concept.
- A variety of MPEG-7 conformant descriptors that can be used to search for images based on image content rather than text annotations were developed and implemented.
- Algorithms for the automatic classification of images into pre-defined categories were developed.

Competencies

Development of algorithms and hardware architectures for image and sound compression (MPEG-2, MPEG-4, H.26L).

Development of algorithms and hardware architectures for 2D and 3D image analysis and synthesis using motion, stereo and multiview information.

Image segmentation, feature extraction and classification.

Development of applications based on MPEG-2/4/7 and JAVA for interactive services over the Internet, over DVB/DAB/DMB, over ISDN, over xDSL, and over mobile networks (DECT, GPRS, HSCSD, UMTS).

Coding methods for videophones and video conferencing (H.26x, MPEG-4).

MPEG and ITU-based signalling and transport protocols (H.32x, MPEG2-TS, DMIF).

Streaming technologies for video and audio over the Internet and wireless channels.

Development and design of integrated circuits for image processing.

Design, integration and implementation of prototypes and experimental systems for video-based applications in communication and for tests and demonstrations of new communication technologies and hardware architectures.

Modelling and development of integrated circuits for image processing.

Development of 3D display technologies.

Conception and evaluation of user interfaces for multimedia applications using VRML, JAVA, MSDL and dVS.

Analysis and optimization of communication terminals and services on the basis of human factors and usability criteria.

Development of video-based pattern recognition and photogrammetry methods.

Modelling and development of integrated circuits for image processing.

Design and construction of experimental systems for the development of video-based communication applications and for testing and demonstrating new communication technologies and hardware architectures.

Analysis of human sensory and sensorimotor functions in relation to communication applications.

Expertise in desktop computer graphics design.

Image and video retrieval systems.

Project	Project Manager phone eMail	Provider of Grant/ Contractor Period
Photonic Networks		
KomNet System Integration Office	Godehard Walf +49(0)30-31002-455 walf@hhi.de	BMBF/Industry (KomNet) 5/98 – 4/02
Optical Technologies in Motion for the IST Programme	Erwin Patzak +49(0)30-31002-514 patzak@hhi.de	EU 5/00 – 4/03
Innovation of Photonic and Mobile Communication Network for the Broadband Internet (TansiNet ON)	Godehard Walf/Jürgen Saniter +49(0)30-31002-455/-288 walf@hhi.de/saniter@hhi.de	BMBF 6/00 – 5/03
Performance Monitoring of WDM Channels	Ernst-Jürgen Bachus +49(0)30-31002-586 bachus@hhi.de	DFG 6/99 – 12/01
DWDM and IP	Ernst-Jürgen Bachus +49(0)30-31002-586 bachus@hhi.de	HHI 10/00 – 12/02
Application of Distributed Raman Amplification for WDM Networks	Ernst-Jürgen Bachus +49(0)30-31002-586 bachus@hhi.de	DFG 3/00 – 5/01
Terabit Metro Ringnetworks – Application and Physical Limits of WDM Techniques	Ernst-Jürgen Bachus +49(0)30-31002-586 bachus@hhi.de	Freunde des HHI 10/00 – 9/01
System Aspects and Tests for Cityring Networks	Ernst-Jürgen Bachus +49(0)30-31002-586 bachus@hhi.de	BMBF/Industry (KomNet) 1/01 – 12/01
Design of Switchable Optical Networks	Ernst-Jürgen Bachus +49(0)30-31002-586 bachus@hhi.de	BMBF (UMTS) 4/01 – 3/03
Frequency Selective Integrated WDM Receiver	Thomas Hermes +49(0)30-31002-455 walf@hhi.de	DFG 8/99 – 7/02
40 Gbit/s OTDM for KomNet	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.de	Industry /KomNet 7/99 – 4/02
Optical Time Domain Multiplex Technique for the Internet of the Future	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.de	BMBF 8/99 – 7/02

Optical Sampling of High Bitrate Data Signals	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.de	DFG 5/00 – 4/02
Gain-Clamped Optical Amplifier in Fibre-optical Transmission Systems	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.de	DFG 4/98 – 3/02
Active Resonant Grating-Waveguide Structures for Rapidly Tuning Semiconductor Lasers with no Moving Elements	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.de	BMBF 8/00 - 7/03
Saturable-absorber Switch	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.de	DFG 3/00 – 2/02
Technological Developments for High Speed OTDM Transmission Systems	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.de	HHI 8/99 – 7/02
160 Gbit/s Transmission Techniques	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.de	Industry 4/00 – 12/02
High-bitrate Optical Signal Processing	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.de	Industry 7/01 – 3/02
High-frequency Selfpulsation of Multi-section DFB Laser	Bernd Sartorius +49(0)30-31002-508 sartorius@hhi.de	BMBF 2/01 – 7/03
TOPRATE	Bernd Sartorius +49(0)30-31002-508 sartorius@hhi.de	EU 9/01 – 8/04
Optical 3R Regeneration for Asynchronous IP Networks	Bernd Sartorius +49(0)30-31002-508 sartorius@hhi.de	BMBF 7/01 – 6/04
Technical Development for OTDM Demultiplexers	Michael Schlak/Bernd Sartorius +49(0)30-31002-407/-508 schlak@hhi.de/sartorius@hhi.de	HHI 1/98 – 12/03
160 Gbit/s 3R Regenerator	Michael Schlak +49(0)30-31002-407 schlak@hhi.de	Industry 11/01 – 6/04
40 Gbit/s Wavelength-Converter	Michael Schlak +49(0)30-31002-407 schlak@hhi.de	Industry 11/00 – 10/01
Design of Switching Characteristics in Dispersive Q-switch Semiconductors	Bernd Sartorius +49(0)30-31002-508 sartorius@hhi.de	DFG 2/01 – 6/02

Semiconductor Saturable Absorber Structures for Femtosecond demultiplexer	Harald Künzel +49(0)30-31002-546 kuenzel@hhi.de	MBI/HHI 11/98 – 3/02
Development of BH-Laser	Martin Möhrle +49(0)30-31002-724 moehrle@hhi.de	HHI 4/99 – 12/01
Development of DFB-BH-Lasers	Martin Möhrle +49(0)30-31002-724 moehrle@hhi.de	Industry 1/01 – 10/01
LED-Arrays	Anagnostis Paraskevopoulos +49(0)30-31002-527 paraskevopoulos@hhi.de	Industry 6/00 –3/01
LED-Array Modules	Anagnostis Paraskevopoulos +49(0)30-31002-527 paraskevopoulos@hhi.de	Industry 4/01 –10/01
Low-Cost Transceiver-PIC for the Access Network	Helmut Heidrich +49(0)30-31002-538 heidrich@hhi.de	BMBF/Industries (KomNet) 6/98 – 4/02
Innovative Lasers and Filters on InP Using Ring Oscillators	Helmut Heidrich +49(0)30-31002-538 heidrich@hhi.de	BMBF 4/00 – 3/03
ps-OEIC	Helmut Heidrich +49(0)30-31002-538 heidrich@hhi.de	BMBF 10/00 – 9/03
Development of Twin Photodiode-Photoreceivers for a 40 Gbit/s TDM Field Experiment in KomNet	Heinz-Gunter Bach +49(0)30-31002-503 bach@hhi.de	BMBF/Industry (KomNet) 5/98 – 4/02
40 Gbit/sPhotoreceiver Module Development for the GIGATRANS-PORT Field Experiment in KomNet	Heinz-Gunter Bach +49(0)30-31002-503 bach@hhi.de	BMBF/Industry (KomNet) 6/98 – 5/01
40 Gbit/s Frontend Development for an ETDM Long Haul Transmission in KomNet	Heinz-Gunter Bach +49(0)30-31002-503 bach@hhi.de	BMBF/Industry (KomNet) 6/98 – 5/01
GaAs-Based 1300 nm Laser	Harald Künzel +49(0)30-31002-546 kuenzel@hhi.de	HHI 7/99 – 6/02
Lattice-matched MBE-growth of (In,Ga)As/(In,Al)As- and (In,Ga)As/Al(As,Sb)-structures on InP for Intersubband Emitters	Harald Künzel +49(0)30-31002-546 kuenzel@hhi.de	DFG 9/00 – 8/03
Material Development for IR-LEDs	Peter Wolfram +49(0)-30-31002-233 wolfram@hhi.de	State of Berlin 1/00 – 6/01

Micro-Filter in Silica-on-Silicon Technology for Optical Communication	Berndt Kuhlow +49(0)30-31002-448 kuhlow@hhi.de	BMBF 4/00 – 3/03
Planar integrated Waveguide-network on Silica	Berndt Kuhlow +49(0)30-31002-448 kuhlow@hhi.de	HHI 1/01 – 6/03
Development of Arrayed Waveguide Gratings	Margit Ferstl +49(0)30-31002-430 ferstl@hhi.de	Industry 10/00 – 9/01
Development of Innovative and Competitive Technologies as a Preliminary Step towards Industrial Fabrication of Optoelectronic Components and Communication Systems in Berlin	Udo Niggebrügge +49(0)30-31002-550 niggebruegge@hhi.de	State of Berlin 10/99 – 12/01
Development of Advanced Technologies for Ultrafast Photoreceivers	Udo Niggebrügge +49(0)30-31002-550 niggebruegge@hhi.de	HHI 6/98 – 5/01
Electro-optical Modulators	Karl-Otto Velthaus +49(0)30-31002-645 velthaus@hhi.de	State of Berlin/HHI 6/00 – 11/01
80 Gigabit Modulator Module	Karl-Otto Velthaus/ Herbert Venghaus +49(0)30-31002-645/-555 velthaus@hhi.de/venghaus@hhi.de	BMBF (UMTS) 5/01 – 12/03
AWG Based on Polymer	Norbert Keil +49(0)30-31002-590 keil@hhi.de	HHI 1/01 – 12/02
Integrated Optical Add/Drop Multiplexer Based on Polymer Technology	Norbert Keil +49(0)30-31002-590 keil@hhi.de	BMBF 6/01 – 5/04
Advanced Packaging Technologies for Highest Frequency Opto-Electronic Components	Thomas Rosin +49(0)30-31002-221 rosin@hhi.de	BMBF (UMTS) 4/01 – 12/03
Development and Realization of Photodiodes	Wolfgang Schlaak +49(0)30-31002-519 schlaak@hhi.de	Industry 7/01 – 9/02
Mobile Broadband Systems		
TransiNet – Innovative Transport Networks for the Broadband Internet (TV)	Holger Boche +49(0)30-31002-540 boche@hhi.de	BMBF 6/00 – 5/03
Teletraffic Engineering for Packed Switched Services	Holger Boche +49(0)30-31002-540 boche@hhi.de	HHI 6/00 – 5/03

Multiuser Receiver for CDMA Systems	Holger Boche +49(0)30-31002-540 boche@hhi.de	HHI 6/00 – 5/03
Sequences in CDMA Systems	Holger Boche +49(0)30-31002-540 boche@hhi.de	DFG 7/00 – 6/02
Uplink-Space-Time Array Processing for 3G WB/CDMA	Martin Schubert +49(0)30-31002-870 schubert@hhi.de	Industry/Freunde des HHI 9/99 – 12/01
MULTIMODE: MIMO Techniques and Antennas	Clemens v. Helmolt +49(0)30-31002-506 helmolt@hhi.de	HHI 9/00 – 12/03
Intelligent Multi-Element Antenna- and Non-Orthogonal Multicarrier-Systems for Modern Broadband Mobile Communication	Clemens v. Helmolt +49(0)30-31002-506 helmolt@hhi.de	BMBF 11/00 – 12/03
Optically Controlled Array Antennas for Wireless Cellular Broadband Networks	Gerd Großkopf +49(0)30-31002-317 grosskopf@hhi.de	BMBF 5/00 – 4/02
Optical Beamforming Network on SiO_2/Si	Gerd Großkopf +49(0)30-31002-317 grosskopf@hhi.de	HHI 5/00 – 4/02
Optical Beam-formed Antennas for Adaptive Broadband Fixed and Mobile Wireless Access Networks	Gerd Großkopf +49(0)30-31002-317 grosskopf@hhi.de	EU 12/00 – 11/03
Design of Pilot-Assisted and Blind Beamforming Algorithms for Space-Time Rake Receivers	Andreas Kortke +49(0)30-31002-872 kortke@hhi.de	Industry/Freunde des HHI 4/00 – 12/01

Electronic Imaging Technology for Multimedia

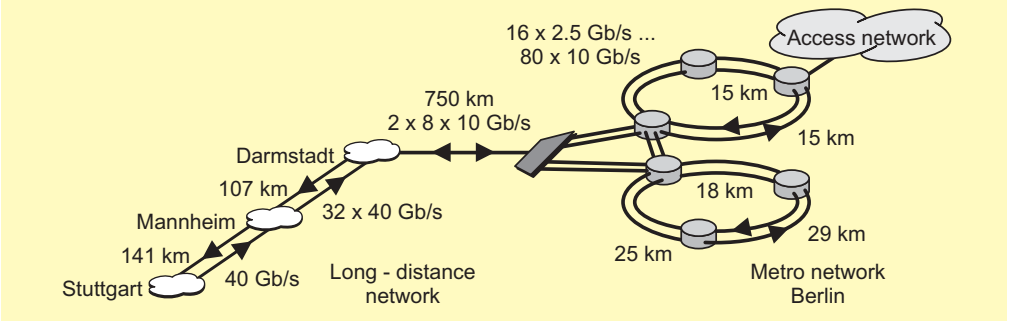
DFN Giga-Media-Services for Cooperative Post-Production of Film and Video	Ralf Schäfer +49(0)30-31002-560 schaefer@hhi.de	DFN-Verein/ Industry 11/99 – 10/01
Algorithms for a 3D-Realtime Video Conferencing System with high Telepresence	Ralf Schäfer +49(0)30-31002-560 schaefer@hhi.de	DFG 6/00 – 6/02
Multi View Synthesis of N Parallel Stereo Rigs	Ralf Schäfer +49(0)30-31002-560 schaefer@hhi.de	DFG 1/01 – 12/02
Video Coding Using 2D and 3D Object and Motion Models	Jens-Rainer Ohm +49(0)30-31002-560 schaefer@hhi.de	DFG 6/99 – 5/01
Feature Based Coding and Similarity Analysis of 3D Objects and Scenaries	Jens-Rainer Ohm +49(0)30-31002-560 schaefer@hhi.de	DFG 12/99 – 11/01

Scalable Videocoding by Wavelets and Fractal Techniques	Jens-Rainer Ohm +49(0)30-31002-560 schaefer@hhi.de	DFG 1/00 – 12/01
Technologies for Hybrid Scene Composition in Interaktive Tele-presence	Peter Kauff +49(0)30-31002-615 kauff@hhi.de	HHI 1/00 – 12/02
Immersive Telepresence in the Internet	Peter Kauff +49(0)30-31002-615 kauff@hhi.de	BMBF 7/00 – 6/03
Interoperability for Video Communication over Distributed Networks, INVINET	Guido Heising +49(0)30-31002-226 heising@hhi.de	Industry 1/99 – 3/02
Dynamic Radio for IP Services in Vehicular Environment	Guido Heising +49(0)30-31002-226 heising@hhi.de	EU 4/00 – 3/02
Immersive TV	Uli Höfker +49(0)30-31002-569 hoefker@hhi.de	Industry 7/99 – 10/01
Technologies for Immersive Television Systems	Uli Höfker +49(0)30-31002-569 hoefker@hhi.de	HHI 1/01 – 6/01
Digital Cinema/Distribution and Projection Technologies	Uli Höfker +49(0)30-31002-569 hoefker@hhi.de	BMBF 7/01 – 3/02
Key Components for User Configurable Terminals, KOKON	Maati Talmi +49(0)30-31002-293 talmi@hhi.de	BMBF 1/99 – 6/02
Bluetooth- and MPEG-4-based Key Components for Mobile Systems	Maati Talmi +49(0)30-31002-293 talmi@hhi.de	BMBF (UMTS) 5/01 – 12/03
Hardware and Software Architectures for Multimedia Terminals, SIPROS	Karsten Grüneberg +49(0)30-31002-262 grueneberg@hhi.de	Industry 5/99 – 2/01
Programmable HYbrid TV System with Integrated CoreS – PHYSICS	Karsten Grüneberg +49(0)30-31002-262 grueneberg@hhi.de	Industry 1/01 – 3/02
Virtual Views for Immersive TV Applications	Christoph Fehn +49(0)30-31002-611 fehn@hhi.de	DFG 1/00 – 12/01
Systems for Advanced Multimedia Broadcast and IT Services	Peter Stammnitz +49(0)30-31002-570 stammnitz@hhi.de	EU 1/00 – 12/01
Virtual Team User Environment	Oliver Schreer +49(0)30-31002-620 schreer@hhi.de	EU 1/00 – 12/02

Open Multimedia Streaming Architecture	Detlev Marpe +49(0)30-31002-619 marpe@hhi.de	BMBF (UMTS) 4/01 – 12/03
Optical Information Systems for Traffic Analysis and Traffic Control/ Videobased Traffic Monitoring	Aljoscha Smolic +49(0)30-31002-232 smolic@hhi.de	BMBF 9/01 – 12/03
Metadata for Advanced Scalable Video Coding Tools	Aljoscha Smolic +49(0)30-31002-232 smolic@hhi.de	EU 1/01 – 12/02
Image Analysis and Recognition in Information Systems	Thomas Wiegand +49(0)30-31002-617 wiegand@hhi.de	BMBF 6/01 – 5/04
3D System with Multimodal Interactions	Siegmund Pastoor +49(0)30-31002-345 pastoor@hhi.de	BMBF 1/99 – 12/01
A Communication Platform for Informal and Computer Supported Communication in Telework and Telecooperation	Lothar Mühlbach +49(0)30-31002-237 muehlb@hhi.de	BMWi 1/99 – 5/02
Roomancer System: Evaluation of the KICK Browser in Terms of Usability	Lothar Mühlbach +49(0)30-31002-237 muehlb@hhi.de	Industry 5/00 – 8/01
EuroInfo@Berlin	Jens Faber +49(0)30-31002-235 faber@hhi.de	State of Berlin 1/00 – 12/01
Intelligent and User-adaptive Systems for Navigation and Retrieval of Images	Thomas Meiers +49(0)30-31002-218 meiers@hhi.de	BMWi 1/99 – 3/02
Image Recognition and Segmentation for Multimedia Applications	Thomas Sikora +49(0)30-31002-210 sikora@hhi.de	DFG 1/99 – 12/01
Sensing People – Intelligent Cameras and Sensors	Thomas Ellerbrock +49(0)30-31002-663 ellerbrock@hhi.de	BMBF (UMTS) 6/01 – 12/03

KomNet – on the Way to the Next Generation Internet

Under the framework of the German R&D initiative KomNet, an industry-based consortium is developing and examining key technologies needed for the implementation of future multi-vendor multi-client dense wavelength division multiplexing (DWDM) communication networks. The KomNet projects have made considerable progress in implementing and testing optical networking technologies, network elements, subscriber loops and protocols under real-life operating conditions, and excellent results have been achieved. HHI contributes to KomNet with several R&D projects and the Systems Integration Office.



German KomNet testbed topology. The entire network has been demonstrated by Acterna, Alcatel SEL, Lucent Technologies, Infineon Technologies, Siemens and T-Systems Nova.

A consortium of industrial partners in Germany, consisting of Acterna, Alcatel SEL, Infineon Technologies, Lucent Technologies, Siemens, T-Systems Nova and VPI Systems, currently collaborates, together with 18 research institutes, universities and SMEs, on developing and field-trialling optical networking technologies, network elements, components, protocols and access network technologies [1]. A complete demonstration communication network, using an in-place Standard Single Mode Fibre infrastructure provided by T-Systems Nova, has been implemented and demonstrated. The system, which comprises a long distance network, a metropolitan network and access networks, interconnects various locations in the cities of Berlin, Darmstadt, Mannheim, and Stuttgart.

One part of the long-distance network is based on N x 40 Gb/s DWDM systems (with N up to 32), equipped by different vendors. For example, foward error correction and distributed Raman amplification have been studied. The work has also focussed on 10 Gb/s systems. A single-fibre bidirectional 16 x 10 Gb/s transmission system is used to bridge the 750 km distance between Darmstadt and Berlin. With an eye to the more distant future, field experiments with ultra-high data rates up to 160 Gb/s (single channel) have been carried out successfully on a 116 km network segment.

In the city of Berlin a managed optical metropolitan DWDM network has been implemented. This test bed consists of two transparently interconnected bidirectional line-switched rings that are equipped with dynamically reconfigurable optical add-drop multiplexers (OADMs, up to 80 channels at 10 Gb/s) and fully managed opto-electronic IP-optimised nodes. In addition, burst-mode transmission and automatic switching of optical network nodes (ASON) have been field-trialled by the consortium.

For access networks, the work has focussed on innovative digital access techniques suitable for transporting data signals at up to 8 Mb/s via twisted pair lines (xDSL), provision of high-quality multimedia services via hybrid fibre-coax networks, optical code division multiplexing feeder lines (up to 1.25 Gb/s per channel, e.g. Gb-Ethernet), and packet-oriented hybrid-fibre-radio systems.

As described in more detail in the following contributions, HHI contributes to KomNet as a subcontractor to industry with several projects on the design and simulation of optical networks, evaluation of network elements, ultra high-speed TDM transmission up to 160 Gb/s, 40 Gb/s photodetectors and receivers, all-polymer OADMs, optical signal regenerators (3R), transceiver photonic ICs, and picosecond opto-electronic ICs.

Also, the KomNet Systems Integration Office at HHI oversees the implementation of the demonstration network and the field trials. The work is supported by the industrial partners, and is partly funded by the German Federal Ministry of Education and Research under grant 01 BP 805.

For more information see
http://www.hhi.de/komnet/

Klaus-Dieter Langer (langer@hhi.de)

TransiNet – Innovative Transport Networks for the Broadband Internet

The joint research project TransiNet aims to develop new concepts for carrying IP traffic over wavelength-division multiplexed (WDM) and wireless networks. This contribution gives a short overview of the TransiNet project.

Two important developments in optical communications networks can be observed:

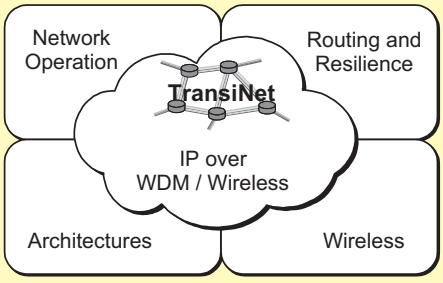
- In recent years the bandwidth available on optical fibres has increased by orders of magnitude, mainly due to wavelength-division multiplexing (WDM) technology.
- The exponential growth of traffic generated by the Internet is causing a paradigm shift in optical networking away from circuit switching towards packet switching.

The objective of the joint project TransiNet (started in June 2000) is to develop new networking technologies to carry IP traffic over WDM optical networks in an efficient manner.

The partners in the TransiNet research project are:

- Heinrich-Hertz-Institut für Nachrichtentechnik Berlin GmbH (HHI)
- Universität Stuttgart, Institut für Nachrichtenvermittlung und Datenverarbeitung (IND)
- T-Systems Nova GmbH, Technologiezentrum (T-Systems Nova)
- TU Berlin, Institut für Nachrichtentechnik und Theoretische Elektrotechnik, Fachgebiet Telekommunikationsnetze (TKN)
- TU München, Lehrstuhl für Kommunikationsnetze (LKN)

Cooperation between the partners is organized into the working groups shown in the figure.



Focal Points in TransNet

Focal points in TransiNet

The main research areas for the next-generation optical Internet in the TransiNet project are new concepts for network and node architectures and the corresponding protocols, standards and technologies, traffic aggregation, scalability of WDM networks, quality of services (QoS), network management, resilience, and the interworking and integration of high-speed photonic and mobile communication systems.

As there are still many technological problems in optical packet switching, optical wavelength-switching, and probably later optical label switching (OLS) or optical burst switching (OBS), are considered to be the next steps towards more dynamic optical networks.

Advanced optical subsystems for optically switched dynamic networks are being investigated in the HHI Department of Optical Networks (ON), including WDM transmission, add-drop multiplexers, optical cross-connects, and wavelength router/switches. Their interworking with higher-layer protocols, manly IP, is also being studied.

Parts of an IP-optimized air interface are being developed in the Department of Broadband Mobile Communication Networks (BM). The main research areas are new signal processing algorithms, prediction of the radio channel, resource allocation, and teletraffic techniques for use in the planning process.

In October 2001 an open workshop was organized by the HHI together with all TransiNet partners. The title of the workshop was “How dynamic must a future transport network be?”

This work is supported by the Federal Ministry of Education and Research under grant 01 AK 020A.

For more information see www.transinet.de.

Jürgen Saniter (saniter@hhi.de)

Fast Optical Switching in Future IP Networks

Network architectures and enabling technologies for future optical Internet networks are investigated in the TransiNet project.

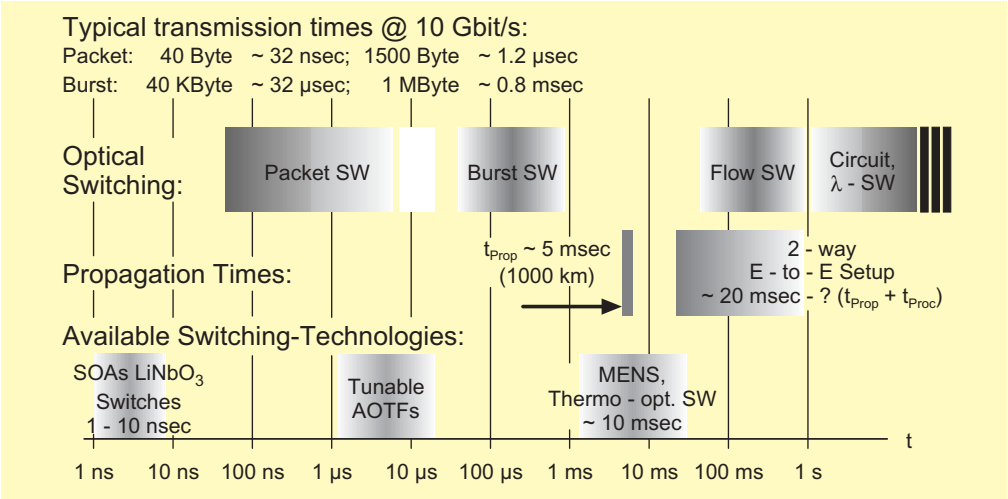
Optical fibres can be operated to carry data at several terabits per second. This leads to a mismatch with the current switching technologies, which are only capable of switching bit rates electronically in the order of several Gbit/s. The objective is to shift the switching burden into the optical domain. The introduction of wavelength-routed optical networks will be the first step. Later architectures using optical burst switching (OBS) or optical packet switching (OPS) might follow.

Depending on the switching frequency, the requirements of the switches vary. In wavelength-routed optical networks, transparent optical paths in the network are switched, depending on the traffic, using tunable optical add-drop multiplexers or optical cross-connects (OXC). Using wavelength-routed connections, every connection will last from a few seconds to several hours. Consequently, the optical switches or multiplexers must have switching times in the range of 10 ms. Micro-electromechanical systems (MEMS) or acousto-optical tunable filters (AOTFs) are capable of accomplishing this and are commercially available.

However, in OBS or OPS networks the data are transmitted in optically switched packages. The average burst length using OBS is in the range of 50 µs, whereas the package length using OPS is in the range of several 100 ns (see the figure). The switches in the optical network nodes have to be fast enough for this high frequency switching. Currently, only semiconductor optical amplifier (SOA) or LiNbO3 switches are capable of achieving these speeds.

Switching times are important in optical networks, but signal degradation also has to be considered, since signal regeneration is expensive and should be avoided whenever possible.

The TransiNet project is investigating the performance of various optical node architectures, including their influence on the signal quality.



Technologies and typical times in optical switched networks

This work is supported by the Federal Ministry of Education and Research under grant 01 AK 020A.

For more information see www.transinet.de.

Jürgen Saniter (saniter@hhi.de)

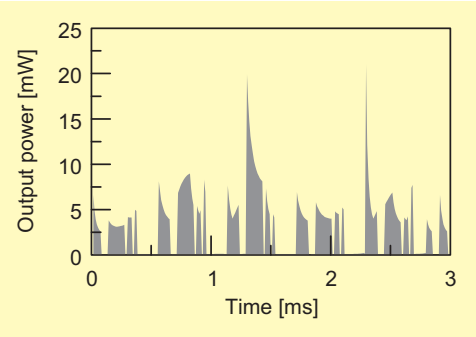
Optical Amplifiers in Wavelength- and Burst-Switched Optical Networks

Dynamic gain changes of erbium-doped fibre amplifiers (EDFAs), which occur if wavelength division multiplexed (WDM) signals or optical bursts are switched transparently through an optical transport network, must be greatly reduced. In a study we have compared and assessed the different ways of stabilising the gains of EDFAs on a time scale of microseconds.

The first step in implementing optical switching is the introduction of optical add/drop multiplexers (OADM) and optical crossconnects (OXC), which dynamically switch wavelength channels. In such a network the number of channels used in a fibre may vary randomly. To use the network more efficiently, the next step might be to implement optical burst and packet switching, so that even the power of a single channel will no longer be constant but will change on a time scale corresponding to the lengths of the bursts and the gaps between them.

When EDFAs are used in networks with bursts or WDM channels that are randomly turned on and off, the gain will change in response to the input power variation. This gives rise to dynamic power excursions of the channels used, thus leading to a degradation of the optical signal-to-noise ratios and bit error rates of the channels.

Figure 1 shows a simulation result for the output power of one of eight WDM channels, each carrying random bursts, after a cascade of seven EDFAs. Crosstalk and large power excursions are observed.



Optical power of one of eight WDM channels after a cascade of seven EDFAs

There are basically two methods of keeping the gain of the amplifiers in a link constant.

The first method is to adjust the pump power. This can be done either by using a feedback control loop or by forward control. In the latter case the pump power is changed according to the measured input power. In the feedback control loop case the gain is measured and the pump power is adjusted.

The second method is to inject an additional saturating optical signal into the EDFA and thereby adjust the gain. Once again, the power in the additional channel can be adjusted by either feedback or feedforward control. Feedback control can be implemented all-optically (gain-clamped optical amplifier). If the extra channel is within the flat gain region of the EDFA, the feedforward control method keeps the optical input power constant. In this case the method can be used to stabilise a whole link with a cascade of optical amplifiers.

Our study lead to the following conclusions:

- If some channels are operated continuously, very large power excursions are eliminated, but control is still necessary.
- At present the best method seems to be to use fast electronic gain control for each amplifier. The control should be a feedback loop with the pump power adjusted according to measurements of the amplifier gain using suitable monitor outputs. The feedback signal can be filtered electronically to optimise the total dynamic response and to avoid the oscillations of gain that are observed with the all-optical control method. This method makes efficient use of the available pump power (unlike an optically stabilised EDFA where most of the pump power is converted into the lasing wavelength) and also allows fine control and adjustment of the EDFA gain without sacrificing any of the EDFA transmission bandwidth.
- The link control method, which uses an extra channel to compensate for the power variations, is less expensive and might fulfil the quality requirements for moderately long amplifier cascades and a moderate number of channels.

Erwin Patzak (patzak@hhi.de)

Control Modulation Technique for Client-Independent Performance Monitoring and Channel Identification in Transparent Optical Networks

A new in-channel monitoring technique for transparent networks using a high-frequency digital control signal for optical performance monitoring and channel identification is investigated by experiments and simulations. The overhead channel serves as an early warning function for client channel performance degradation due to transmission impairments.

Optical performance monitoring and channel identification independent of the electrical client signal is a key issue for the management of future all-optical networks. Performance monitoring is necessary to determine the quality of a transparent light path independent of the client signal. Channel identification is essential for future switched transparent networks to ensure proper routing in optical add-drop multiplexers and optical crossconnects.

The new control modulation technique can be used to monitor both identity and quality of the single wavelength channel. Unlike previously known techniques, e.g. optical signal-to-noise ratio (OSNR) measurement or the Q-factor method, the control modulation technique predicts the quality of optical transmission independently of the electrical client, and also with a higher accuracy, since even degradation due to pulse distortion is taken into account.

The principle of the new method are shown in Figs. 1 and 2. The control signal is a low-bitrate digital signal upconverted to frequencies above the payload modulation spectrum and is added to the payload signal using an additional optical modulator. To monitor quality and identity at the network nodes, a small amount of the composite signal is tapped off and fed to a control signal receiver.

Figures 3 and 4 show experimental results from loop measurements with a 10 Gb/s payload and a 50 Mb/s control channel. The quality correlation for optimum transmission parameters up to transparent distances of 2500 km is shown in Fig. 3. The transparent reach may be further extended by the use of forward error correction (FEC) in the control channel. While the payload channel remains error free with a slight power penalty, the measured BER in the control channel degrades significantly. Figure 4 illustrates the early warning function of the control channel for transmission impairment due to self phase modulation (SPM).

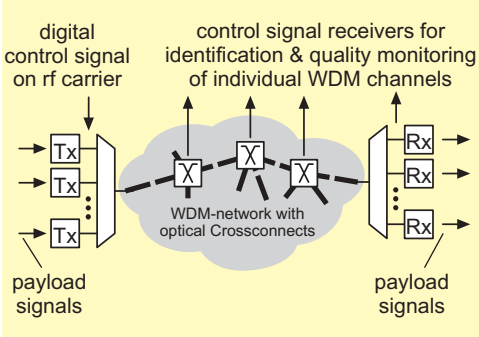


Fig. 1:
Application of the control modulation technique in a transparent WDM network with optical crossconnects

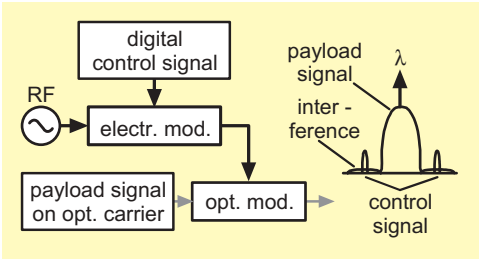


Fig. 2:
Insertion of the control signal and the optical spectrum

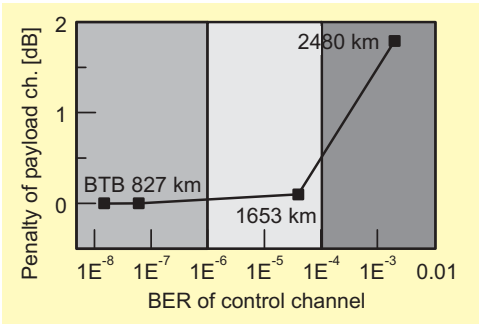


Fig. 3:
Quality correlation for transmission parameters set to optimum.

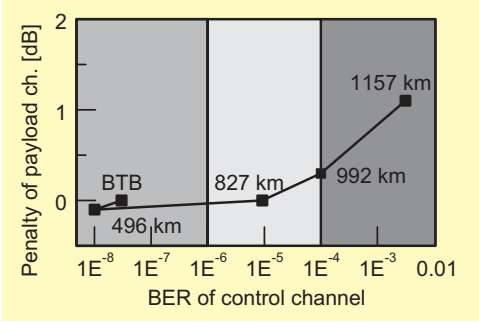


Fig. 4:
Quality correlation for transmission impairment due to self phase modulation (SPM).

[1] M. Rohde, "HF-Prüfmodulation zur Signalkontrolle in WDM-Netzen", 2. ITG-Fachtagung Photonische Netze, pp. 165-168, 12-13 March 2001, Dresden.

Michael Rohde (michael_rohde@hhi.de)

Potential and Implementation of Non-Zero Dispersion Shifted Fibres (NZDSF) in Long Haul Transmission

New fibre types such as NZDSF are receiving more attention as the bit rates are rising. Simulation results for future 40 Gbit/s NRZ transmission systems are presented for dispersion-optimised transmission links using NZDSF. To test the compatibility with existing standard single mode fibre (SSMF) links, experiments are performed with a mixed setup of SSMF and LEAF® links at 10 Gbit/s.

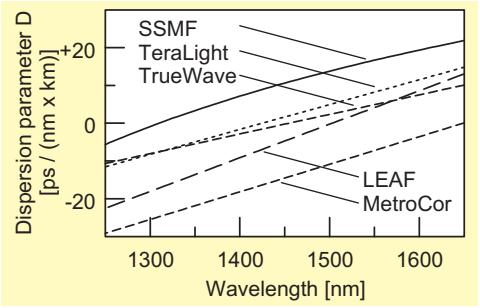


Fig. 1: Dispersion parameters of various fibre types including NZDSF

New fibre types with different dispersion features are currently being implemented in optical networks (Fig. 1). Of special interest for long-haul high bitrate applications is NZDSF (LEAF®, TeraLight™, TrueWave®).

We have investigated the potential of LEAF at 40 Gbit/s using the simulation tool TransmissionMaker from VPIsystems. The simulated transmission link consists of symmetrically compensated LEAF sections, with the section length equalling the amplifier spacing. A contour plot showing the transmission length for varying section power and section length is given in Fig. 2. The large transmission length can be achieved using a short-period dispersion compensation scheme 10 km long. This reduces the pulse dispersion in NZDSF and also gives less irreversible pulse distortion due to self phase modulation.

Network providers are looking for a migration path from SSMF-only networks to a next generation networks including NZDSF. Hence it is of major interest to evaluate the performance of a mixed setup of SSMF and NZDSF links. We have investigated the special case of alternating SSMF and LEAF sections for 10 Gbit/s NRZ signals. This link setup is shown in Fig. 3.

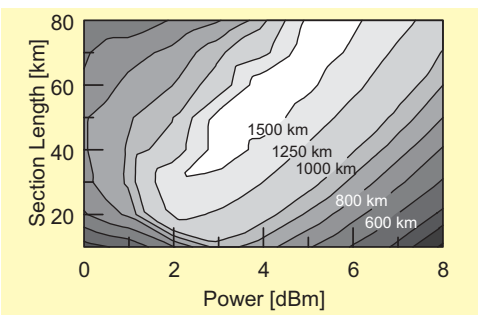


Fig. 2: Contour plot of transmission length as a function of the fibre input power and section length. The simulation is at 40 Gbit/s with dispersion-optimised LEAF sections of up to 1500 km transmission lengths.

For this setup the dependence of the system penalty on length is shown in Fig. 4. The single channel case reaches a transmission length of 4000 km with a 2 dB penalty. This is actually slightly better than a SSMF-only link [1]. The 3-channel case with a channel spacing of 200 GHz reaches 3000 km, and for the 5-channel case with 100 GHz channel spacing a transmission length of 2000 km is reachable. The additional penalty for the WDM transmissions is caused by cross phase modulation (XPM), as shown in [1]. The SSMF-only setup and the mixed SSMF and LEAF setup reach comparable transmissions lengths, thus demonstrating the compatibility of SSMF and LEAF sections in a link.

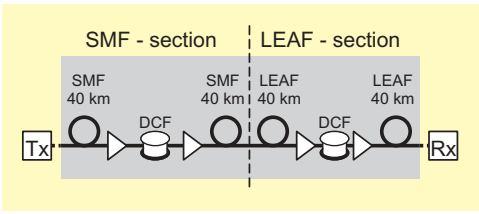


Fig. 3: Setup for mixed standardised sections

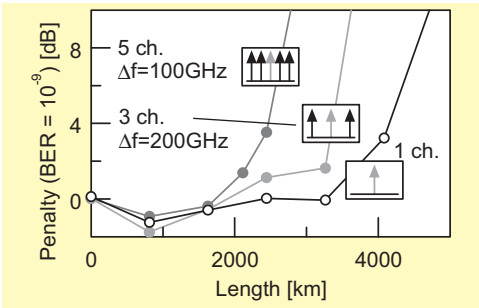


Fig. 4: Penalty of mixed LEAF and SSMF links for single channel transmission of 10 Gbit/s NRZ signals. This shows the increasing influence of XPM for decreasing channel spacing for WDM transmission

[1] C. Caspar et. al, "Penalties through XPM crosstalk in a switched long haul standard fiber WDM system based on normalized transmission sections", OFC 2001, Anaheim, USA, 18.-22. March, Techn. Dig., paper WI5.

Kai Habel (habel@hhi.de)

10 Gb/s NRZ Transmission over 4000 km Using All-Distributed Raman-Amplified Transmission Links Without Lumped Amplifiers

NRZ transmission at 10 Gb/s over the record length of 4000 km has been demonstrated using all-distributed Raman-amplified links without the use of erbium-doped fibre amplifiers (EDFAs), FEC or solitons. Large Raman amplifications of 58 dB in long-haul transmission links have been achieved. Link simulations show good agreement with the experiments.

With increasing demand on transmission capacity, distributed Raman amplification (DRA) in conjunction with EDFAs has become a very important technique in broadband high-speed wavelength division multiplexed (WDM) transmission systems, including the L-band and S-band. Long-haul transmission over 8000 km with hybrid amplification (DRA and EDFAs) and over 4000 km with solitons and distributed Raman amplification have been reported.

The work carried out at the HHI concentrated on all-distributed Raman amplified links without EDFAs, forward error correction (FEC) or solitons [1]. The main objectives of our investigations were to prove whether long transmission distances can be achieved with Raman amplification only and to find what properties can be expected from these links, compared with those using EDFAs and hybrid amplification. The problems of implementing high-gain Raman amplification in the system and of modelling the amplification process had to be solved. Simulations of the links show good agreement with the experiments (done in cooperation with VPIsystems Inc., Berlin).

To evaluate the properties of a WDM transmission system using all-Raman amplification, we performed 10 Gb/s NRZ WDM transmission experiments with up to 16 channels in our loop testbed (Fig. 1). The loop consisted of 171 km of sSMF and 28 km of DCF and used pre and post dispersion compensation. High-gain distributed Raman amplification of 58 dB was applied to compensate for the losses of the fibres and components. To achieve this high gain and to avoid severe Rayleigh back-scattering of the pump power in the fibres, the sSMFs and DCFs were pumped at five points with a 1455 nm Raman fibre laser of up to 3.4 W and a 1447 nm diode laser at 0.24 W. The pump power for the fibre laser was split by couplers into four parts (30 %, 30 %, 20 % and 20 %).

Figure 2 shows the BER as a function of the received power for transmission over distances from 1000 to 4000 km. The all-Raman-amplified transmission over 4000 km without EDFAs, FEC, and solitons is, to the best of our knowledge, a record transmission length.

These transmission results show that long distances can indeed be bridged with all-Raman amplification and that further optimisations might lead to similarly good results as with EDFA and hybrid amplification. Raman amplification has the advantage that it has a much larger amplification band and better dynamic behaviour when the system operates in a switched or burst mode.

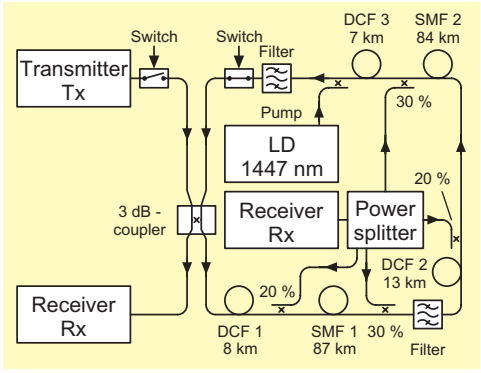


Fig. 1:
WDM loop testbed with all-distributed Raman amplification (10 Gb/s WDM transmission system)

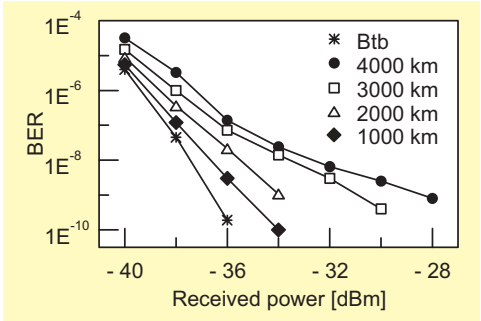


Fig. 2:
BER for the 10 Gb/s NRZ transmission over 1000 km to 4000 km

This work was funded by the Deutsche Forschungsgemeinschaft under grant Ba 1790/2-1.

[1] E. Schulze, R. Freund, M. Malach, F. Raub "10 Gb/s NRZ transmission over 1826 km multiple pumped distributed Raman amplified transmission link without lumped amplifiers", ECOC 2001.

Elmar Schulze (schulze@hhi.de)

Application of 80 GHz All-Optical Clock Recovery in a 160 km Transmission Experiment

Clock recovery is a key function for signal processing in OTDM systems, which have a theoretically predicted speed potential of 160 Gb/s, and even higher for self-pulsating PhaseCOMB lasers. A first optical clock recovery device is fabricated and tested in an 80 Gb/s transmission experiment over 160 km. Jitter of less then 300 fs is measured, indicating the good system performance of the optical clock.

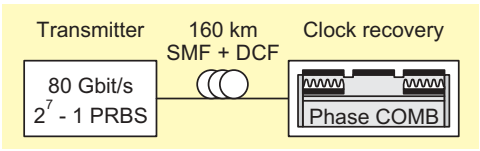
Clock recovery following a transmission link is an essential function for subsequent signal processing functions. With ever increasing data rates, optical signal processing and optical clock recovery covering the 40 to 160 GHz range is of current interest, e.g. for full optical 3R regeneration (Re-amplification, Re-timing, Re-shaping) [1]. A novel type of self-pulsating laser, the PhaseCOMB (Phase Controlled Optical Mode Beating), has an extremely high speed potential beyond 160 GHz, as predicted by modelling [2]. The PhaseCOMB laser is based on a 1.55 µm multi-section DFB laser structure. It consists of two DFB sections (detuned by about the stop bandwidth) and an integrated phase tuning section. Self-pulsations are generated with frequencies defined by the detuning of the gratings and by the driving dc currents. For all-optical clock recovery the data signals are simply injected into the device, whose self-pulsation frequency is adjusted close to the data rate. The synchronisation is insensitive to wavelength and polarisation, and the good system performance of this clock recovery device has been demonstrated at 40 Gb/s.

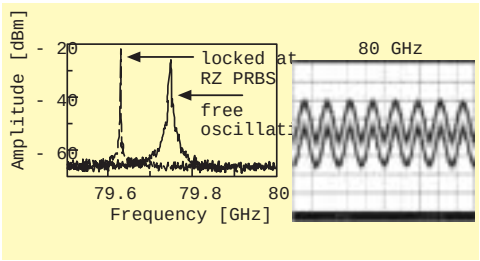
Fig .1: Setup for the 160 km transmission experiment

For 80 GHz applications a new PhaseCOMB laser was fabricated. The device is packaged into a module for testing the system performance in a transmission experiment over 160 km (Fig. 1). The data signal was generated using a mode-locked laser emitting transform-limited pulses with a width of 1.1 ps at a repetition rate of 9.953 GHz and a wavelength of 1550 nm. A PRBS signal was encoded onto RZ pulses using a $LiNbO_3$ modulator and passively multiplexed into a 80 Gb/s PRBS of length 2^7–1. It was launched into a fibre link consisting of 160 km of a single mode fiber and a matched length of dispersion compensating fiber. At the receiver side the signal was injected into the PhaseCOMB laser. The output pulse trace of the recovered clock was analysed using an ultra fast photodetector (u^2t) and a 50 GHz RF analyser (Agilent), upgraded in bandwidth by using a selected mixer. Figure 2 (left) shows the how the free running self-pulsation synchronises to the data rate with a narrowed line width, indicating the locking function. The synchronised clock pulse trace measured using an oscilloscope is shown in Fig. 2 (right).

Fig. 2: Analysis of locking function: RF spectra (left) and pulse trace (right), triggered by the data signal

The most important parameter of a clock is the timing jitter, which is analysed via phase noise measurements with the RF analyser. The jitter analysis was performed for both the optical clock and the data source in order to evaluate the measuring system and to compare the jitter values. The rms jitter was 238 fs for the data signal from the mode-locked laser and 282 fs for the recovered clock, which is only a slight increase. The mode-locked laser has been already been applied successfully in transmission experiments up to 160 Gb/s and thus represents a very high quality reference standard. The similar jitter value from the 80 GHz optical clock demonstrates an excellent system performance.





[1] B. Sartorius, OFC 2001, paper MG7, Anaheim, Cal., USA, March 2001.

[2] M. Möhrle, IEEE J. Sel. Topics QE, vol. 7, no.2, March/April 2001, pp. 217-223.

Carsten Bornholdt (bornholdt@hhi.de)

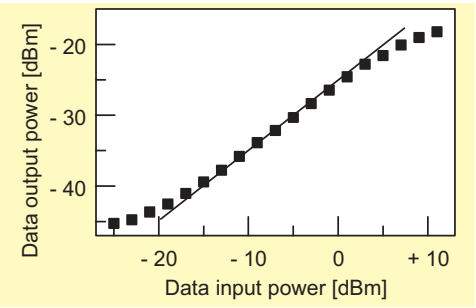
Monolithically Integrated All-Optical Demultiplexer for 160 to 10 Gbit/s

Monolithically integrated Mach-Zehnder interferometers (MZI) will be essential for advanced all-optical signal processing in the ultrafast optical communication networks that will be used by the coming information society. Error-free all-optical demultiplexing from 160 Gbit/s to 10 Gbit/s is performed here using a MZI with monolithically integrated band-gap-shifted semiconductor optical amplifiers (GS-SOAs).

Monolithically integrated interferometers require various types of optical elements: high gain SOAs, low-loss compact bends and couplers, efficient couplers with small reflections between active and passive sections, and low-loss fibre couplers. These have been realised by using buried hetero-structure amplifiers with butt-coupled passive buried waveguides, leading to the worlds smallest integrated MZI switch with dimensions 4.5 x 1 mm^2 (Fig. 1).

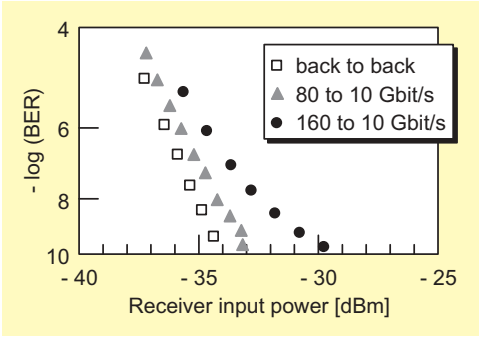
The MZI is used with a differential control scheme, in which both amplifiers are saturated separately with a controllable time delay, resulting in an adjustable switching window.

Key components of the MZI are the SOAs in a 'band gap shifted' (GS) configuration with a gain maximum at a wavelength of 1.5 µm, which is far from the data, which are in the 1550 nm wavelength range [1].



This configuration gives high phase shift efficiency, good contrast ratio and good linearity. Figure 2 shows experimental results for the switched output power as a function of the data input power. Linear dependence is observed over a range of 20 dB, which is limited only by the amplified spontaneous emission at low input powers and by gain saturation of the SOAs at high input powers. The switching performance of the all-optical switch in the linear range is independent of the data input power.

The switching performance of the MZI switch could be demonstrated in error-free 160 to 10 Gbit/s all-optical demultiplexing experiments for all channels (Fig. 3). MZI device modules have been realised in cooperation with the packaging group of the HHI, and have been used in system testbeds at Alcatel and HHI.



Due to its potential, the monolithically integrated MZI will play an important role as a basic building block in advanced all-optical signal processing functions such as decisions, comparisons, correlations, sampling and signal conversion. One main future objective will be the application of the MZI switch as a synchronous modulator in a soliton supported 3R regeneration scheme at clock frequencies up to 160 GHz.

[1] T. Tekin, M. Schlak, W. Brinker, B. Maul and R. Molt, Proc. of 26th Europ. Conf. Opt. Commun., vol. 3, pp. 123-124, September 3-7, 2000.

Michael Schlak (schlak@hhi.de)

Fig. 1:
The world's smallest all-optical demultiplexer: A symmetric Mach-Zehnder interferometer with monolithically integrated band-gap-shifted semiconductor optical amplifiers

Fig. 3:
Error-free all-optical demultiplexing performance with a GS-MZI

Fig. 2:
Linearity of monolithically integrated MZI

Optical Sampling of 160 Gb/s Eye Diagrams in an 80 km Transmission Experiment

We measured 160 Gb/s eye diagrams after 80 km fibre transmission using a complete optical sampling system. The system comprises an all-optical clock recovery device and a sampling gate based on a nonlinear optical loop mirror (NOLM).

In-service quality monitoring of high bit-rate optical transmission systems can be achieved at the full line rate by using optical sampling systems. These systems provide the picosecond timing resolution needed to record eye diagrams of 160 Gb/s data signals.

Figure 1 shows the experimental setup of the transmission experiment. A 160 Gb/s optical RZ data signal is transmitted over an 80 km unrepeatered fibre span of standard single mode fibre (SSMF). The optical sampling system, which is used to measure the eye diagram of the optical data signal, is shown in the enlarged detail.

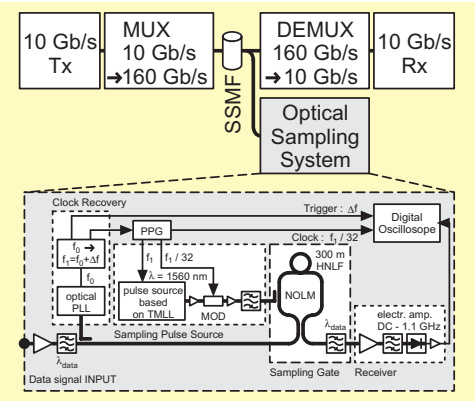


Fig. 1: Schematic of the optical sampling system and its application for eye diagram monitoring in an 80 km transmission experiment

Part of the signal is used for clock recovery at the input of the sampling system. The clock recovery device contains an optical PLL with a semiconductor laser amplifier in an optical loop mirror (SLALOM) gate as an ultrafast optical mixer [1]. The extracted 10 GHz base rate of the optical time-division multiplexed (OTDM) data signal is frequency shifted by Δf = 10 kHz to the frequency f_1 using the RF carrier-suppressed single-sideband modulation technique. The sampling pulse source contains a tunable mode-locked semiconductor laser (TMLL). It operates at the pulse repetition rate f_1 and delivers 1.5 ps sech^2 pulses with an rms timing jitter of 0.3 ps (λ = 1560 nm). The sampling pulse rate is reduced to 310 MHz by a $LiNbO_3$ Mach-Zehnder modulator (MOD) driven by a frequency divider (PPG, pulse pattern generator) because of the limited clock speed of the digital oscilloscope. The sampling gate is a nonlinear optical loop mirror (NOLM) containing 320 m of highly nonlinear fibre (HNLF, λ_0 = 1547 nm) [2]. The average input powers of the sampling pulses and data signal are about –5 dBm and +14 dBm, respectively. The switched output signal of the NOLM (i.e. the optical samples) is fed into a low bandwidth receiver. The peak powers of the optical samples are detected and displayed as an eye diagram on a digital oscilloscope with an external clock input.

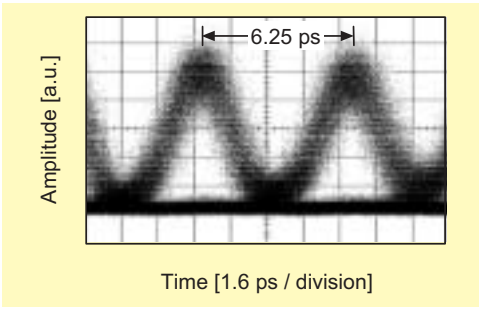


Figure 2 shows a typical 160 Gb/s eye diagram measured by the optical sampling system. Due to the excellent timing resolution of the system, the different channels in the data signal are clearly resolved. The switching window of the sampling gate determines the shape of the eye diagram. Thus there is no visible ringing. The use of a clock recovery device in the sampling system gives persistence times that are large enough to enable the collection of sufficient statistical data for a quantitative evaluation of the eye diagram, by Q factors for example.

[1] T. Yamamoto et al., "Clock recovery from 160 Gbit/s data signals using a phase-locked loop", Electron. Lett., 37(8), 509-510, (2001).

[2] S. Watanabe et al., "All-optical signal processing using highly-nonlinear optical fibers", IEICE Trans. Electron., E84-C(5), pp. 553, (2001).

Carsten Schmidt
(carsten.schmidt@hhi.de)

160 Gbit/s Optical Clock Recovery Device and its Application in an Optical Demultiplexer

We report on an optical clock recovery device, based on an optical phase-locked loop (PLL), for 160 Gbit/s optical time-division multiplexed (OTDM) data signals. This device was successfully operated in a 160 to 10 Gbit/s optical demultiplexer in a 120 km fibre transmission experiment.

Clock recovery is an essential operation in both receivers and regenerators in transmission systems. We succeeded in developing a PLL-based clock recovery device for 160 Gb/s data signals using a semiconductor laser amplifier in a loop mirror (SLALOM) as the optical phase comparator [1]. We examined its performance in a 160 Gbit/s OTDM demultiplexer in a fibre transmission experiment over a link length of 120 km.

Figure 1 shows the setup, including the clock recovery device, of the demultiplexer from a 160 Gbit/s OTDM signal to a 10 Gbit/s signal. In the clock recovery unit, the SLALOM acts as a fast phase comparator between the 160 Gbit/s data signal and the 10 GHz optical clock pulses generated locally by a tunable mode-locked laser (TMLL). The feedback loop locks the frequency of the optical clock to the base-rate frequency of the data signal. The timing jitter of the recovered optical clock was less than 0.3 ps. Owing to the two Erbium-doped fiber amplifiers (EDFAs) in front of the clock recovery unit, which worked in the saturated region, the clock recovery device locked to 160 Gbit/s data signals over the wide power range -30 dBm to +5 dBm at the input of the demultiplexer, without readjustment of the unit. The optical switch for demultiplexing was a gain-transparent ultrafast nonlinear interferometer (GT-UNI) – i.e. the SOA in the GT-UNI had its gain peak in the 1300 nm wavelength range, so that it was transparent for the data signals. The switching contrast was more than 20 dB. The width of the switching window was about 5 ps.

We confirmed that the PLL did not cause a power penalty in the demultiplexer, and succeeded in error-free transmission over a 120 km fibre (see Fig. 2). This demultiplexer is thus a promising candidate for future ultra-high speed OTDM systems.

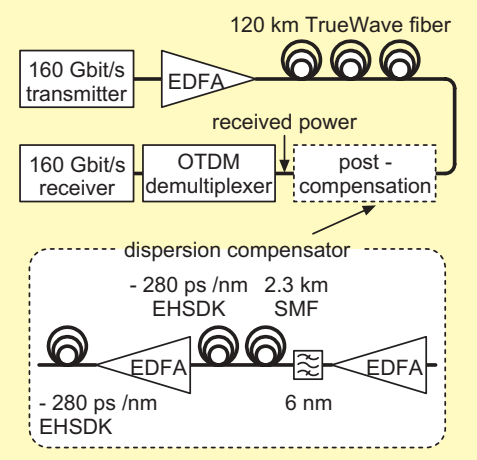


Fig. 2:
Setup of the 160 Gbit/s transmission experiment using a demultiplexer with clock recovery device

[1] T. Yamamoto, L.K. Oxenløwe, C. Schmidt, C. Schubert, E. Hilliger, U. Feiste, J. Berger, R. Ludwig and H. G. Weber, "Clock recovery from 160 Gb/s data signals using a phase-locked loop", Electron. Lett., vol. 37, no. 8, pp. 509-510, 2001.

Hans-Georg Weber (hgweber@hhi.de)

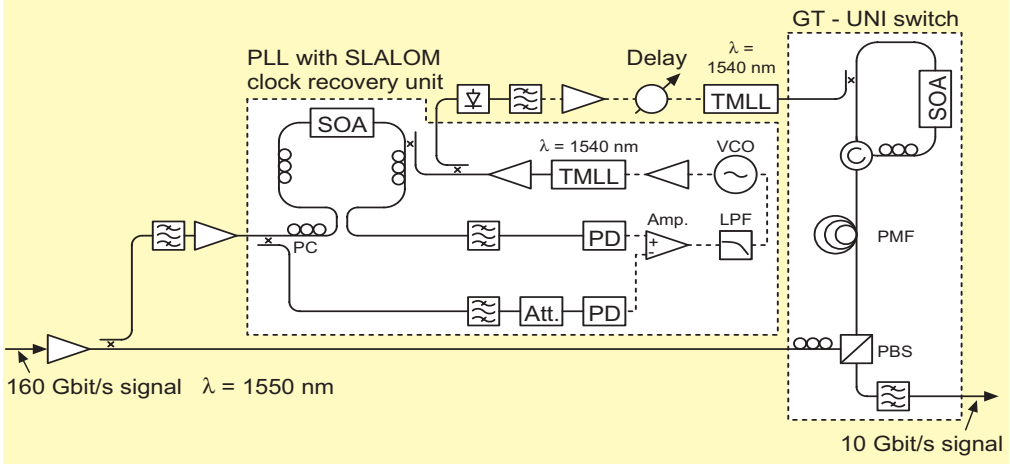


Fig. 1:
Setup of the 160 Gbit/s demultiplexer with clock recovery device using two SOA-based interferometric switches

Automatic Polarization-Mode Dispersion Compensation for 80 Gbit/s Data Transmission over Installed Single Mode Fibre

We report on 80 Gbit/s transmission over 45 km of installed fibre using automatic polarization-mode dispersion (PMD) compensation. To our knowledge, this is the first demonstration of a PMD compensator at this speed. This work is a cooperation between HHI and the Technical University Hamburg-Harburg FSP 2-03 Optical Communications (E. Brinkmeyer, H. Rosenfeldt and R. Ulrich).

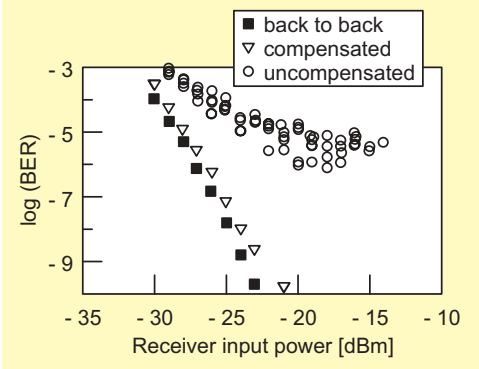
Polarization-mode dispersion causes severe signal impairments in high bit-rate optical transmission systems. For bitrates higher than 40 Gbit/s automatic PMD compensation is required. A critical issue is the response time of the differential group delay (DGD) element of the PMD compensator. The group at the Technical University Hamburg-Harburg applied open loop feedforward control of the compensator, in which the link DGD is continuously measured and fed forward to a variable DGD element in order to set the appropriate DGD of the compensator in a single step. Continuous DGD monitoring was realized by a polarization-resolved measurement of the degree of polarization (DOP) combined with a polarization scrambler at the fibre input. This allowed the DGD of the link to be continuously monitored, and the dependence on the input polarization was eliminated.

BER performance

Using this PMD compensator, we performed 80 Gbit/s RZ data transmission over a PMD-compensated installed fibre link in the city of Berlin of 45 km length with an average DGD of 6 ps [1]. The PMD compensator comprised two controllers, one for the motor-driven variable DGD element and one for the polarization controller, which was based on piezo-driven fibre squeezers. The variable DGD element was controlled by continuously measuring the minimum DOP at the input of the delay line. A stored response curve was used to calculate the link DGD. This value directly controlled the DGD of the compensator in the feedforward structure. The second controller used the measured DOP at the delay line output for feedback control.

The figure shows the bit-error rate (BER) performance of the system with pattern length 2^7-1.

At the operating wavelength the instantaneous DGD was about 3.7 ps. Without PMD compensation, an error floor occurs at a BER of 10^{-6} and error-free transmission was not possible.With PMD compensation, we obtained error-free transmission with a penalty of less than 1 dB, compared to the back-to-back measurements. To our knowledge, this is the first demonstration of a PMD compensator at 80 Gbit/s.



We have demonstrated that a feedforward approach for PMD compensation avoids the need for dithering and allows the compensator DGD to be adjusted in a single step. DOP evaluation combined with polarization scrambling provides access to link parameters such as DGD and principles states of polarization.

[1] H. Rosenfeldt, R. Ulrich, E. Brinkmeyer, U. Feiste, C. Schubert, J. Berger, R. Ludwig, H. G. Weber and A. Ehrhardt, “Feed-forward approach for automatic PMD-compensation at 80 Gbit/s over 45 km installed single mode fiber”, 27th European Conference on Optical Communication (ECOC), 30 Sep – 4 Oct 2001, post-deadline.

Hans-Georg Weber (hgweber@hhi.de)

Development of InP Modulators Based on a Travelling Wave Electrode Design for 40 Gbit/s and Beyond

An InP-based modulator with an electrical bandwidth above 50 GHz has been developed. Current research activities are directed towards an industrial process with good reproducibility and high yield. Currently under development is the integration in hybrid form of a driver IC into a modulator module.

Over the past decade, as the demand for telecommunication services and bandwidth has boomed, the advantages of external modulation in fibre-optic transmission systems have been firmly established. Indium phosphide (InP) modulators based on a Mach-Zehnder interferometer (MZI) structure with a travelling wave electrode (TWE) design can give high data rates of 40 Gbit/s and beyond, as well as zero-chirp designs and an optical bandwidth of 30 nm. In addition, due to the highly efficient quantum-confined Stark effect (QCSE) used by the modulator, its structure is much smaller (< 3 mm^2) and needs less driving voltage (V_{PP} ~ 2V) than comparable devices made with GaAs or lithium niobate. This inherently low driving voltage is one of the key issues for future transmission rates of 80 Gbit/s and higher.

The schematic layout of the modulator is shown in Fig. 1, which shows the two TWE electrodes, which are designed as microstrip lines. Their overall impedance can be matched to 50 Ω by the capacitive load of the distributed electrodes on the MZ arms. So far an electrical bandwidth of 50 GHz has been achieved [1] with this design, but further improvements up to modulation speeds of 160 Gbit/s should be possible in the near future.

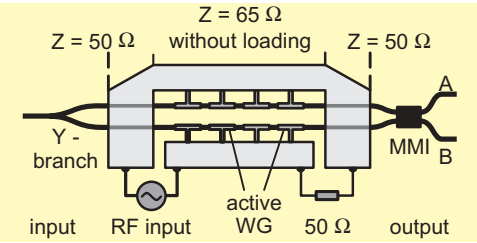


Fig. 1:
Schematic layout of an MZI-based modulator with capacitively loaded travelling wave electrodes

The cross section of an MZI is shown in Fig. 2. The layers with various material sequences and the electrical equivalent circuit are indicated schematically. The reverse-biased PN junction of the MZI is shown as the capacitive load of the TWE electrode.

In the scanning electron microscope (SEM) photo of Fig. 3 one can see parts of this TWE electrode and the MZI waveguides (WG) with two active sections, including waveguide electrodes and connecting strips as air bridges spanning the isolation ditches.

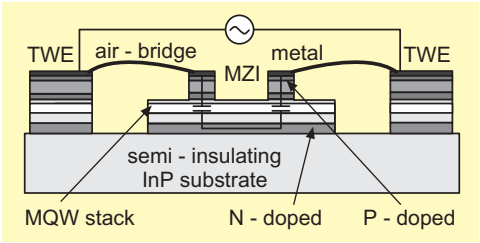


Fig. 2:
Cross-sectional view of an MZI and the TWEs with schematic electrical equivalent circuit

Fig. 3:
SEM Photo showing parts of the TWE electrode; a pair of air bridge connections between TWEs, and two waveguide diodes

The optical design of this modulator also includes an optical mode transformer for cleaved fibre coupling with low insertion loss.

This 40 Gbit/s modulator concept is now being developed as an industrial process with good reproducibility. The manufacturing partner for this work is u2t Photonics GmbH.

Future developments will include a hybrid integration of the modulators together with their driver electronics. This will be the basis of new TWE and modulator designs that could achieve transmission rates up to 80-160 Gbit/s.

This work was supported by the State of Berlin (874700001) and the Federal Ministry of Education and Research under grant 01 AK 936B.

[1] L. Mörl, D. Hoffmann, K. Matzen, C. Bornholdt, G. G. Mekonnen and F. Reier, "Travelling wave electrodes for 50 GHz operation of opto-electronic devices based on InP", Proc. IPRM, 1999, pp. 385-388.

Karl-Otto Velthaus (velthaus@hhi.de)

Ultrafast Optical Nonlinearity at Wavelengths around 1.55 µm of GaInAs/AlInAs Quantum Wells Grown at Low Temperatures

The ultrafast optical response of GaInAs/AlInAs multiple quantum wells grown at low temperatures was studied in pump-probe experiments. Experiments with pairs of ultrashort pulses separated by 1.5 ps demonstrate fast modulation of material transmission and very small accumulation effects.

The availability of III/V materials with ultrafast optical response times and large optical nonlinearities is crucial for future ultrahigh bitrate fibre-based communication systems. To this end various types of optical recombination scenarios may be exploited, one of which, conventional interband transitions in defect-rich bulk or low-dimensional III/V materials, is regarded as attractive. These materials can be achieved with high quality by using molecular beam epitaxy at low growth temperatures (LT), down to 100 °C (cf. HHI annual report 1999). In contrast to the well-established LT GaAs/AlAs material system, the absorption edge of LT GaInAs/AlInAs multiple quantum wells (MQWs) can be adjusted to the 1.55 µm wavelength range used in optical fibre transmission.

Uniform p-doping using Be was demonstrated recently as a method for reducing the optical response times in GaInAs/AlInAs MQWs. Additionally, annealing was considered relevant as for GaAs-based structures because of the formation of clusters of excess As. This effect was found also to occur in GaInAs/AlInAs MQWs, as demonstrated by the transmission electron microscopy (TEM) pictures in Fig. 1.

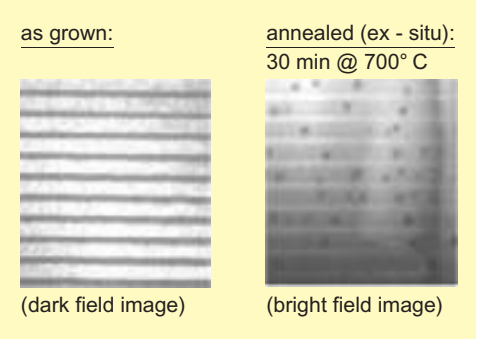


Fig. 1: TEM pictures of the cleavage plane of 100 period GaInAs/AlInAs MQWs grown at 200°C

Significant differences have been found between the absorption recovery times of as-grown and annealed samples. The normalized change of transmission of annealed samples decays with a time constant of approximately 1.5 ps, whereas as-grown samples decay with the much smaller time constant of 230 fs, which reflects the decrease of the excess carrier density due to trapping from conduction and valence band states into localized defect levels.

Pump-probe experiments with pairs of pump pulses with widths of 140 fs and separated by 1.5 ps were carried out to simulate optical switching conditions at very high data repetition rates. As shown in Fig. 2, the sequence of these pump pulses is clearly resolved only in the case of the as-grown Be-doped sample. In the annealed Be-doped sample we observe an accumulation of carriers during the second pump pulse and a substantially slower decay of the transmission change after the second pump pulse.

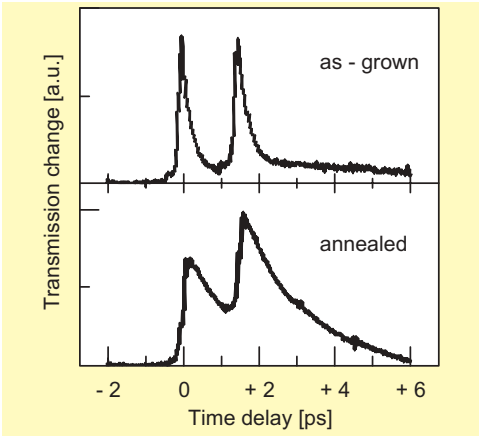


Fig. 2: Ultrafast transmission changes after excitation by a pair of femtosecond pulses separated by 1.5 ps in time

Long-term accumulation effects after long pulse sequences are a problem in optical switches. To further study such phenomena, we performed experiments with simultaneous pulsed and cw excitation at 50 mW incident average power. The annealed Be-doped sample clearly shows accumulation effects, whereas such effects are virtually absent in the as-grown Be-doped sample.

In conclusion, as-grown Be-doped LT GaInAs/AlInAs MQW material is considered to be a highly promising material for all-optical switching, even in the Tbit/s domain.

This work was performed as a joint research effort with the Max-Born-Institut, Berlin, and the Humboldt University of Berlin.

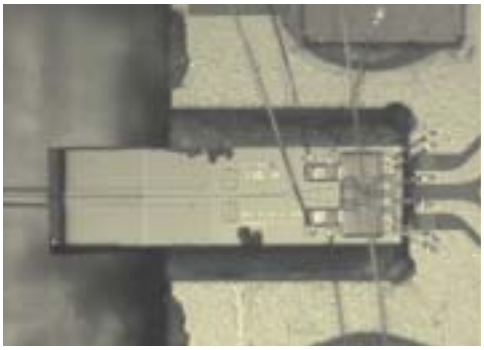
Harald Künzel (kuenzel@hhi.de)

High-Power 1.55 µm Twin-Photodetector Modules for 40 Gbit/s TDM Field Trials

Monolithically integrated twin-photodetectors based on InP were fabricated and mounted into butt-coupled modules. The detectors, with large bandwidths and high optical and electrical symmetry, were successfully used in a high-speed field trial.

For compact integration of 40 Gbit/s optical front ends it is desirable to have a distortion-free and robust detector type that effectively suppresses all electromagnetically coupled interference signals from digital circuitry mounted in the same housing. Our approach is an integrated twin-photodetector, comprising a tapered spot-size converter for efficient fibre to chip coupling, a multimode interference coupler for optical 3 dB power splitting, and two waveguide-fed evanescently coupled high-speed p-i-n photodiodes delivering two symmetrical electrical signals with inverse polarities to the differential inputs of a subsequent electronic circuit.

For the 40 Gbit/s field trials, this photonic integrated circuit was packaged robustly by mounting the photodetector on a ceramic substrate and connecting it with bonding wires to the coplanar stripe lines leading to the two V-connector output ports. A standard single-mode fibre was coupled to the TiO_2-coated input facet of the chip (Fig. 1), which ensures an optical return loss better than 27 dB for the module.



Excellent electrical and optical symmetry, necessary for differential operation, was achieved because of our compact integration concept. The ratio of the photocurrents of the two photodiodes in the detector is less than 0.5 dB for all states of polarization. The total responsivity of the photodetector is 0.41 A/W, with a polarization-dependent loss of only 0.5 dB.

The high-frequency behaviour of the module was studied by injecting high power optical picosecond pulses. Figure 2 shows the received symmetric electrical pulses from the two photodiodes (pulse width 14 ps). These have 0.5 V peak voltages, which are large enough to drive the demultiplexer stage directly. The 3 dB bandwidth of the twin-photodetector module was determined to be 45 GHz with an optical heterodyne setup [1].

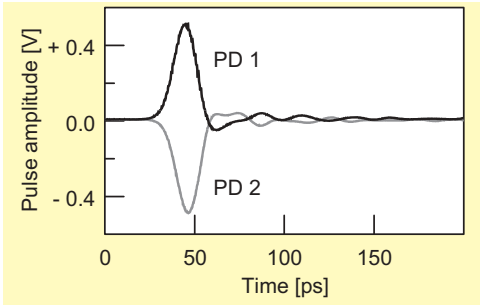


Fig. 2:
Pulse responses of the photodiodes PD 1 and PD 2 in the detector module

Eye diagram measurements were performed by the industry partner and showed clearly opened eyes (Fig. 3). The detector modules were successfully employed in the KomNet project in a 43 Gbit/s (forward error correction) field trial.

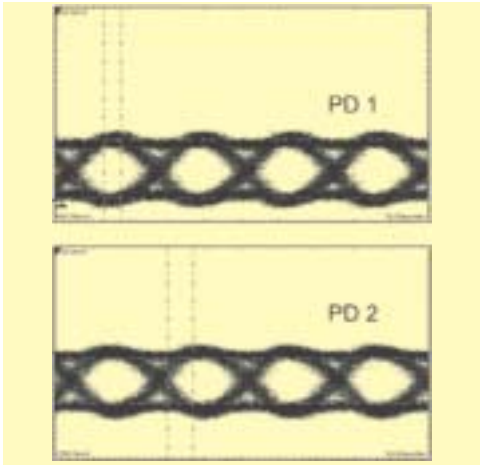


Fig. 1:
Top view of the twin-photodetector module
Fig. 3:
43 Gbit/s eye diagrams of both photodiodes

[1] A. Beling, D. Schmidt, H.-G. Bach, G. G. Mekonnen, R. Ziegler, V. Eisner, M. Stollberg, G. Jacumeit, E. Gottwald, C.-J. Weiske, A. Umbach, "High power 1550 nm twin-photodetector modules with 45 GHz bandwidth based on InP", Proc. Optical Fiber Commun. (OFC 2002) , March 17-22, 2002, Anaheim, CA, USA, paper WN4.

Andreas Beling (beling@hhi.de)

50 GHz Photoreceiver Modules With InP OEICs for FEC 40 Gbit/s Systems

Photoreceivers are key components in high bitrate telecommunication systems. This work describes an InP-based pin diode with travelling wave amplifier (pinTWA) photoreceiver optoelectronic integrated circuit (OEIC) with a monolithically integrated spot-size converter, including its packaging and module performance. Flat gain characteristics, a bandwidth extended to 50 GHz and a fully open eye pattern at 43 Gbit/s are achieved.

The upgrading of high-speed fibre transmission systems to a bit rate of 40 Gbit/s is now in progress. The need for forward error correction (FEC) in data traffic and the demand for faster transmission will require a further extension of the bit rate in each channel. Broadband high-speed photoreceivers are one of the key elements in present and future optical communication systems. This work focuses on the robust and cost effective packaging of single-chip photoreceiver modules with 50 GHz bandwidths.

The ultra-broadband photoreceiver consists of a wave-guide integrated photodiode with a passive optical chip waveguide and a travelling wave amplifier (TWA) using high-electron mobility transistors (HEMT). The addition of an integrated spot-size converter and a redesign of the distributed amplifier circuit improved the receiver bandwidth to 50 GHz (Fig. 2). The overall opto-electric conversion efficiency also increased to 1.1 A/W and the amplifier gain flatness improved to ± 0.8 dB [1]. The transimpedance of the redesigned amplifier, consisting of 4 HEMTs (with power consumption less than 100 mW), is 110 Ω. For antireflection purposes when using a standard single-mode fibre, the optical input facet of the photoreceiver OEIC was coated with TiO_2/SiO_2. Optical coupling is done by fixing the butt fibre directly at the tapered waveguide facet of the OEIC with UV-curable resin.

Fig. 1:
50 GHz single-chip pigtailed photoreceiver module with a pinTWA InP receiver OEIC

The optical return loss was better than 30 dB. This coupling type has high robustness against vibration and thermal cycling under field operating conditions. The coupling efficiency, measured in terms of the responsivity of about 0.6 A/W, remained unchanged after a 10 minute vibration test at 15 g acceleration. The bandwidth of the packaged OEIC is still as high as for the chip alone (50 GHz), and the low ripple behaviour is also unaffected (Fig. 2). The modules were supplied to industry partners in the KomNet program for system characterization. Figure 3 shows a widely opened eye pattern of this photoreceiver in a 43 Gbit/s electrical time division multiplex (ETDM) test bed at Alcatel SEL AG.

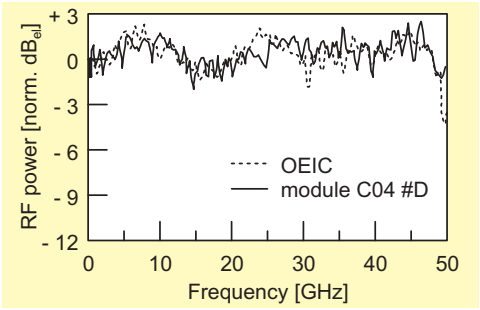


Fig. 2:
Optical heterodyne measurement of the opto-electric power transfer characteristics of the photoreceiver OEIC and of the receiver module with the same OEIC

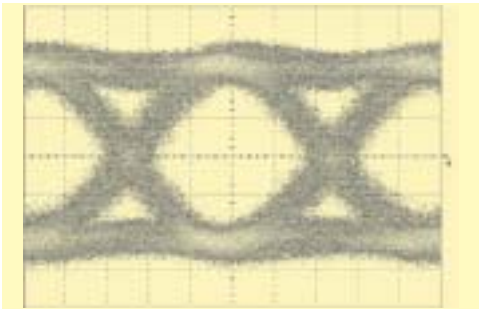


Fig. 3:
Measured eye pattern of a photoreceiver module at 42.6 Gbit/s with NRZ signalling.
x: 5 ps/div, y: 20 mV/div.

[1] H.-G. Bach et al., "50 GHz photoreceiver modules for RZ and NRZ modulation format comprising InP-OEICs", Proc. 27th European Conf. On Optical Communication (ECOC2001), 30 September – 4 October 2001, Amsterdam, The Netherlands, paper Th. M.2.5.

Heinz-Gunter Bach (bach@hhi.de)

Tapered 1550 nm InGaAsP-BH-FP Lasers

Large spot-size laser diodes are required to realise low cost optical transmitter modules. The all-active tapered buried heterostructure (BH) FP lasers developed here combine low threshold currents and high output powers with low fibre coupling losses.

In this project, InGaAsP-BH-FP lasers with a tapered active stripe have been developed and optimised. The investigations focussed on the realisation of lasers with cavity lengths smaller than 500 µm in order to achieve a large number of devices per processed wafer. A second requirement was that the lasers should be able to operate without an additional high-reflection coating of the back facet.

To meet these specifications, the active layer, the waveguide design and the length of the lasers have been optimised [1].

The active layer consists of 6 compressively strained InGaAsP quantum wells separated by tensilely strained barriers. The FP lasers are processed using three MOVPE epitaxy processing steps. Current blocking is achieved using conventional pnp InP blocking layers. The length of the optimised lasers is 400 µm.

Upside-up mounted devices have threshold currents of about 6 mA and more than 40 mW CW output power (Fig. 1). It should be noted that a facet coating was not applied.

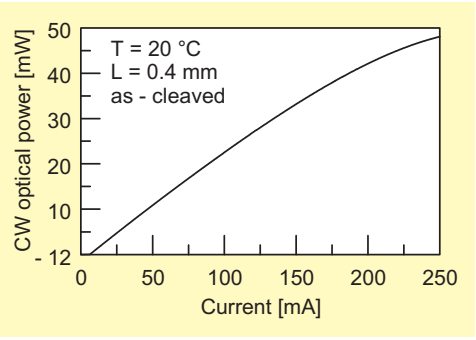


Fig. 1:
CW optical output power at front facet

At 90 °C the threshold current is only about 32 mA, but more than 10 mW output power is still achieved at the front facet. These devices are hence suitable for uncooled operation.

The devices have virtually circular FWHM far field angles of about 17° laterally and 18° vertically. Figure 2 shows the fibre-coupled optical powers of tapered and untapered lasers with coupling to a flat-end single-mode fibre.

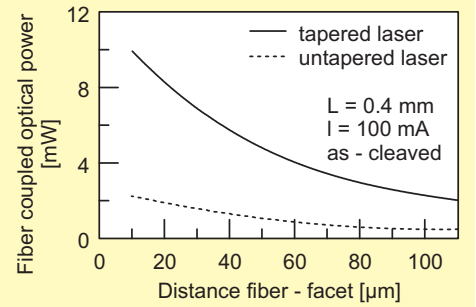


Fig. 2:
Optical power coupled to a flat-end single-mode fibre

The tapered devices achieve 10 mW coupled optical power. The coupling loss of the devices to a flat-end single-mode fibre is -3.5 dB.

The reliability of these devices was confirmed with ageing tests at 85 °C and with an operating current of 100 mA (Fig. 3).

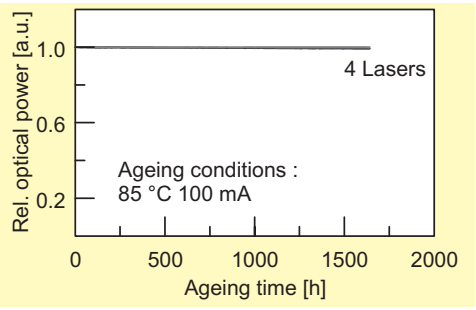


Fig. 3:
Ageing characteristics of 4 tapered lasers

Investigations are now concentrating on optimising the devices for direct modulation at 10 Gb/s.

[1] M. Möhrle, A. Sigmund, A. Suna, H. Roehle, L. Mörl and F. Reier, "High performance all-active tapered 1550 nm InGaAsP-BH-FP lasers", European Semiconductor Laser Workshop, Ghent, Belgium, 28-29 September 2001.

Martin Möhrle (moehrle@hhi.de)

Trade-Off Between High Single-Mode Yield and Low Feedback Sensitivity in DFB RW Laser Arrays

We have developed a four-wavelength laser array with excellent single-mode operation and high power output. By optimising the coupling strength, the single laser yield could be routinely stabilized at about 90 %, giving array yields better than 60 %. The tailored $\lambda_B/8$ phase shift design also helps to maintain this high yield while at the same time satisfying the commercial demand for low feedback sensitivity.

Multiple-wavelength sources are key components of dense wavelength-division multiplexed communication systems. The two main concepts are tunable lasers and laser arrays. Laser arrays require less complex processing, but for statistical reasons an extraordinarily high individual laser yield is required for an adequate array yield. In our project we have applied the phase-shifted distributed-feedback (DFB) ridge waveguide (RW) laser design with index grating [1], which gives good accuracy for the individual wavelengths. The specifications for the 4-λ arrays under investigation are: 400 GHz line spacing, single-mode operation with a side-mode suppression ratio (SMSR) better than 30 dB, and a minimum dc power output of 10 mW at 100 mA driving current.

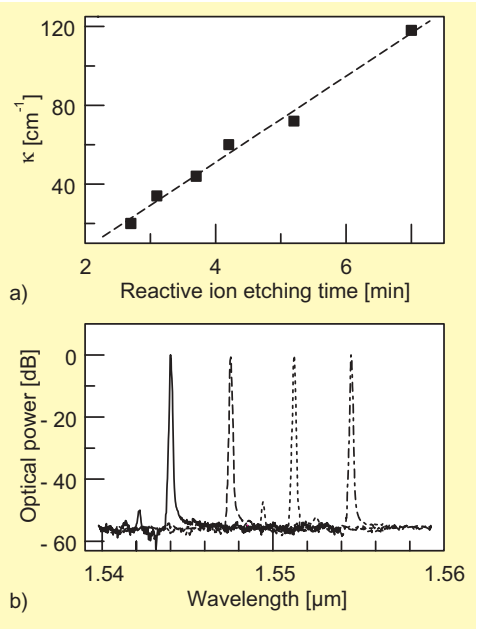


Fig. 1: (a) The linear dependence of the coupling coefficient k on the dry etching time; (b) The spectrum from a four-laser array.

In a first working package the single laser yield for $\lambda_B/4$-shifted gratings (where λ_B is the Bragg wavelength) at various coupling strengths κL has been optimised (where κ is the coupling coefficient and L the laser length). Figure 1b shows the high reproducibility of our grating process. Typical array spectra with very good single-mode behaviour are shown in Fig. 1c. Based on the characterization of more than 600 arrays, the dependence of the individual laser yield of the $\lambda_B/4$-shifted lasers on the coupling strength κL is given by the open circles in Fig. 2. The distinct optimum value of κL lies between 1.2 and 1.5. Away from this optimum the DFB laser yield decreases either because the threshold current increases and the SMSR becomes more sensitive to imperfections (on the lower coupling side), or because, in the stronger coupling regime, the lasers start to degrade due to longitudinal spatial hole burning (LSHB).

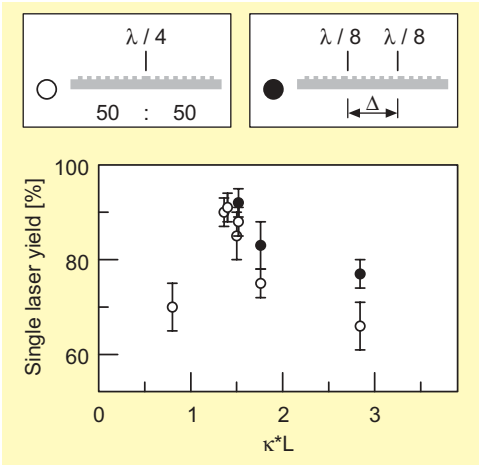


Fig. 2: Laser yield versus coupling strength for $\lambda_B/4$ and tailored $\lambda_B/8$ phase-shifted grating designs. The insets show the two kinds of gratings.

As well as the specifications described above, low feedback sensitivity is also required in system applications. One way to achieve this is to increase κL. To maintain the high yield for κL values above 1.5 we have replaced the $\lambda_B/4$ phase shift by two tailored $\lambda_B/8$ phase shifts. For suitable separation distances (17-30 µm) the LSHB effects could be reduced, giving increased yield compared to the standard $\lambda_B/4$-shifted lasers (Fig. 2, filled circles).

[1] J. Kreissl, U. Troppenz, W. Rehbein, B. Hüttl, E. Lenz, H. Venghaus, F. Fidorra, "High single-mode-yield multiple-wavelength DFB laser arrays in the 1.55 µm range", Proc. ECOC 2001, vol. 2, pp. 118-119.

Jochen Kreissl (kreissl@hhi.de)

Optical Filter and Laser Using GaInAsP/InP Ring Resonators

Network engineers need more components than are available today, especially ones with better performance and increased functionality. Key issues are miniaturization and monolithically integrated optoelectronic and photonic ICs, in particular for components based on GaInAsP/InP.

We present typical results with microring devices used for the realization of compact optical filters. Following the development strategy of first learning from passive devices, then improving their performance by Semiconductor Optical Amplifier (SOA) integration, and finally extending the functionality to all-active structures, we first fabricated a passive double ring device with add/drop functionality (Fig. 1). Two racetrack rings are coupled by a directional coupler (coupling coefficient -13 dB). Input and output coupling are performed by -3 dB multimode interference couplers. The free spectral range (FSR) is 50 GHz (radii 200 µm, ring loss 1.6 dB/mm), and the on/off ratio is 18 dB. Platinum resistors (100 Ω) are integrated to fine tune the temperature. We then integrated an SOA section for loss compensation, since passive devices cannot satisfy the requirement for strong optical crosstalk suppression (> 20 dB) in optical communication systems because of their residual losses. The best on/off ratio so far is 25 dB.

The response of a typical all-active device is shown in Fig. 2. The device can operate in a filter mode (e.g. with I_{Ring} = 50 mA) or in a comb laser emission mode (e.g. with I_{Ring} = 90 mA). In both cases the feeding waveguide and coupler sections are transparent by a current injection I_{tr}. After antireflection coating I_{tr} can be increased so the device can be used as an inline SOA.

Ongoing investigations are focusing on exploiting nonlinear effects in microrings. By proper choice of the injection currents in the feeding waveguide, coupler and ring section it is planned to demonstrate all-optical nonlinear switches and tunable dispersion compensators. It is also planned to realize Wavelength Division Multiplexing (WDM) interleaver multiplexers and demultiplexers by cascading rings of different FSRs.

This work was supported by the Federal Ministry of Education and Research under grant 01 BC 925.

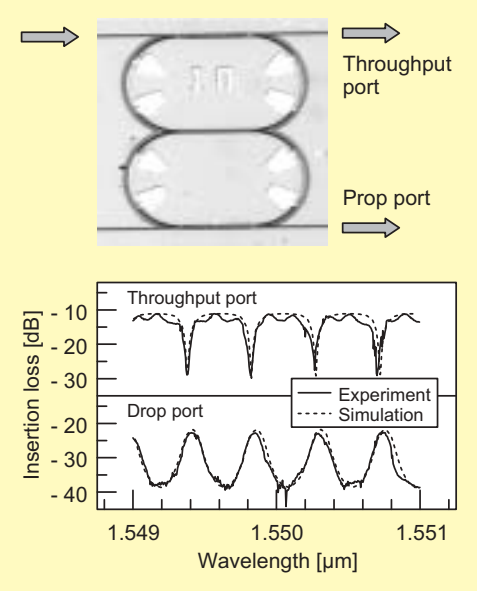


Fig. 1:
Add/drop response and photo of a passive double ring resonator device

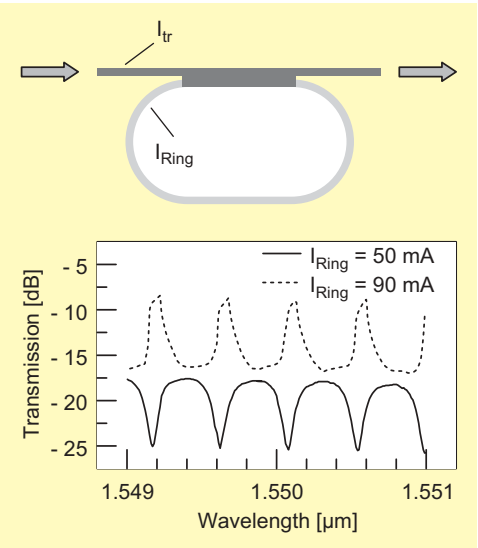


Fig. 2:
Typical filter and comb laser response of an all-active ring resonator

[1] D. Rabus and M. Hamacher, "MMI coupled microring resonators on GaInAsP/InP", IEEE Photon. Technol. Lett., vol. 13, no. 8, pp. 812-814, 2001.

[2] D. Rabus, M. Hamacher and H. Heidrich, "Active and passive microring resonator filter applications on GaInAsP/InP", Proc. IPRM 2001, May 2001, Nara, Japan, pp. 477-480, paper ThA1-3, ISBN 0-7803-6700-6.

Helmut Heidrich (heidrich@hhi.de)

Fabrication of InGaAsP/InP Ridge Waveguide Lasers with Dry Etched Facets

Dry etched laser facets for InGaAsP/InP ridge waveguide (RW) lasers were fabricated using chemically assisted ion beam etching (CAIBE) and a cost-effective photoresist mask without additional treatment. The output characteristics, especially the optical field distribution, were identical to those of lasers with cleaved facets.

Dry etched facets are very attractive for semiconductor laser diode fabrication, since they have the potential for on-wafer device fabrication and thus substantial cost reduction. The chemically assisted ion beam etching technique is commonly used for dry etching, as it offers both vertical sidewall etching and high etch rates. Work in HHI has concentrated on the fabrication of InGaAsP/InP ridge waveguide (RW) lasers with dry-etched facets using a simple photoresist mask.

The mask definition for the facet etching is an important issue, as the masking material must be compatible with the overall fabrication scheme and also cost-effective. In our work we used a 1.4 µm thick layer of photoresist AZ5214, which we patterned using lithographic exposure. There was no additional treatment. Etch selectivity proved to be about 35:1.

The MOVPE grown laser structure comprised a multiple quantum well (MQW) active region with strained InGaAsP QWs emitting at 1.55 µm. Prior to facet etching, 2 µm wide ridges were structured. The photoresist layer efficiently masks the ridge region despite an overall etch depth of about 12 µm, as can be seen in Fig. 1. We could achieve depths of up to 20 µm without any apparent ridge damage. We believe that the good photoresist mask efficiency is due to a baking effect taking place in the CAIBE reactor as the sample is heated to process temperature.

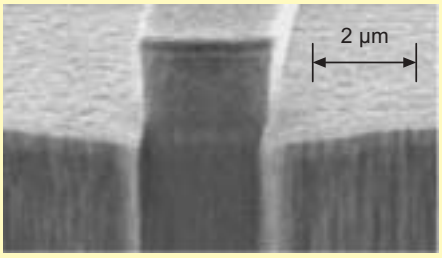


Fig. 1: SEM photos of a RW laser with CAIBE etched laser facets. The photoresist mask has been removed.

Comparison of the devices with etched or cleaved facets showed practically identical output characteristics (Ith = 10-15 mA, Pout@100mA = 12-15 mW). In order to explore the possible influence of the CAIBE process, we systematically evaluated the far and near field distributions of the emitted laser light. A typical comparison for etched and cleaved facets is shown in Fig. 2. No detectable differences could be observed.

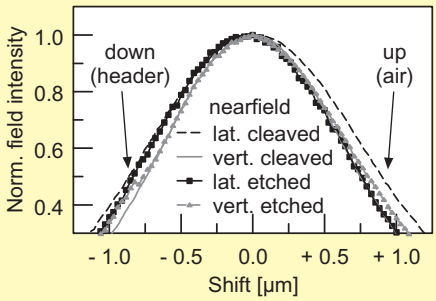


Fig. 2: Comparison of the measured optical far field distribution of the light emitted from a cleaved and a dry-etched laser face.

Another issue for the dry etched facets is the possible accelerated aging of these devices. Aging at 85 °C and 150 mA for 660 hours showed no substantial difference to cleaved facet lasers, all devices having an estimated lifetime at 20 °C of more than 100,000 hours (Fig. 3).

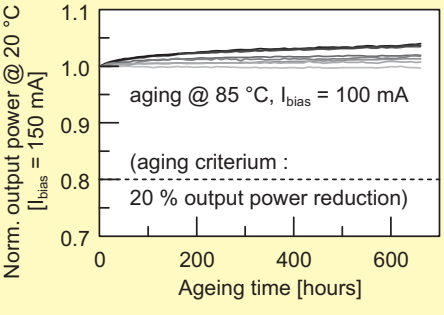


Fig. 3: Aging results with dry etched facet RW Lasers. The estimated lifetime is 10^5 hours at 25 °C.

This work was supported by the Land Berlin and the European Fund for Regional Development.

Anagnostis Paraskevopoulos
(paraskevopoulos@hhi.de)

Polymer-Based Athermal Arrayed-Waveguide Grating Multiplexer

An athermal arrayed-waveguide grating (AWG) multiplexer using an all-polymer approach has been realised. By properly adjusting the coefficient of thermal expansion of the polymer substrate, athermal and polarisation-independent AWG devices featuring a wavelength shift of less than ±0.05 nm in the 25 – 65°C temperature range could be demonstrated.

AWGs based on polymer materials have been gaining increasing attention because polymers have the potential to provide added device functionality and to offer cost benefits. A serious problem with using AWGs in dense wavelength division multiplex (DWDM) systems is the temperature dependence of their channel wavelengths, which means that they require a temperature control unit for thermal stabilisation, an expensive overhead. There is therefore an urgent need to create temperature-insensitive, or passively athermal, AWGs.

Various solutions have been proposed to achieve temperature insensitivity for silica-based AWGs. However, these methods are either somewhat susceptible to performance degradation or somewhat intricate in their use of a moving input fibre. We have introduced an all-polymer approach [1] for realising athermal AWGs that uses polymer materials for both the waveguide structure and the substrate. By properly matching the positive coefficient of thermal expansion (CTE) of the polymer substrate to the negative thermo-optic coefficient of the waveguide material, athermal and polarisation-independent AWGs can be realised.

The fabrication of our AWG devices involves the deposition of the polymer waveguide layers by spin coating, cross-linking by UV exposure, and structuring by means of conventional photolithography and reactive ion etching (RIE). The measured optical loss of a polymer channel waveguide fabricated in this way was less than 0.8 dB/cm in the 1.55 µm wavelength region. The crosstalk level is well below -30 dB, and the insertion loss was between 5.8 dB for the centre port and 7.5 dB for the edge ports. The polarisation shift proved to be less than 0.02 nm without any extra compensation. These results prove the all-polymer AWG has a crosstalk equivalent to that of standard silica AWGs, but superior polarisation dependence (Fig. 1).

To achieve the desired athermal behaviour, a polymer substrate with a CTE of α_{sub} = 80 ppm/K was used. This value can be shown to compensate for the thermo-optic coefficient of the waveguide material, which was $-1.16 \cdot 10^{-4}$/K. Figure 2 shows the measured temperature dependence of our all-polymer AWG, compared with those of a standard silica-on-silicon AWG and of a polymer-on-silicon AWG. The all-polymer AWG has a temperature-dependent wavelength shift of less than ±0.05 nm over the entire temperature range between 25 – 65 °C.

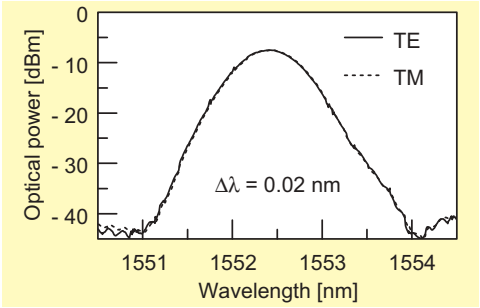


Fig. 1:
Measured polarisation shift of an all-polymer AWG

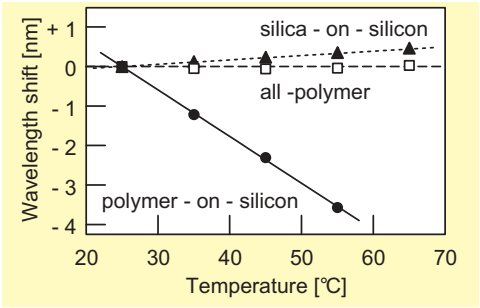


Fig. 2:
The shift in wavelength with temperature for AWGs of various compositions

[1] N. Keil et al., Electron. Lett., vol. 37, pp. 579-580, 2001.

Norbert Keil (keil@hhi.de)

Silica-Based Beam-Forming Planar Lightwave Circuit (PLC)

A novel silica-based optical signal processor for beamforming in smart antenna systems in the 60 GHz frequency range is presented. It is comprised of a phase shifter and an attenuator PLC network utilizing the thermo-optic effect in silica.

Future mobile broadband communication in the 60 GHz frequency range should offer beam tracking between transmitter and receiver to ensure high signal-to-noise ratio. This can be achieved by steerable beamforming with a phased-array antenna by means of amplitude and phase control of the individual millimetre-wave signals feeding the antenna elements. In our experimental system the radio frequency is generated by heterodyning two optical waves (of frequencies ν_1, ν_2) in the 1.5 µm band. This offers the possibility of obtaining the desired phase shifts in the millimetre wave domain, at the beat frequency ν_2-ν_1, by shifting a phase in the optical domain by the same amounts.

We have realised a silica-based PLC for optical beamforming that utilizes the thermo-optic effect for phase control. Planar waveguides of 6 x 6 µm^2 cross-section are embedded between 15 µm thick silica buffer and cladding layers. Each of the two optical input waves in this optical beamforming network (OBFN) is split up by a manifold by y-branches that depends on the number of antenna elements, as shown in Fig. 1a. The straight waveguide sections that follow are covered by metal heater strips on top of the cladding layer. A phase shift of $\Delta\varphi = 2\pi/\lambda \cdot (dn/dT \cdot L \cdot \Delta T)$ in the optical domain is caused by the thermal change of refractive index in silica, with $dn/dT = 10^{-5}$ K^{-1}. The maximum required phase shift for heaters of length L = 10 mm is 2π, allowing for the modulo-2π excitation of the antenna steering. This is achieved by a temperature change of only ΔT = 10 K. The heaters are implemented by 30 µm wide and 200 nm thick platinum stripes with gold bond pads on both ends.

At the OBFN exit the optical waves are combined in pairs using 3 dB couplers. Both the beat frequency ν_2-ν_1 in the millimetre-wave domain and the mean optical frequency appear at the coupler outputs.

The controllable attenuators consist of Mach-Zehnder Interferometers (MZIs) incorporating two 3 dB couplers and thermo-optic (TO) phase shifters, as shown in Fig. 1b. A maximum phase shift of π is required for full signal suppression. The chip size of the complete 4-channel phase shift PLC is about 2 x 30 mm^2 and that of a 4-channel attenuator PLC about 2 x 25 mm^2. Both components were housed and pigtailed and successfully tested in an experimental 60 GHz smart antenna system.

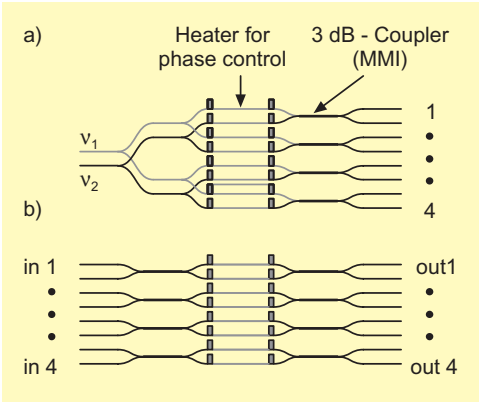


Fig. 1: Layout of 4-channel PLC, each with 2x4 outputs (MMI: multimode interference). (a) Phase control PLC, (b) amplitude control PLC.

Figure 2 shows the obtained phase shift and attenuation for 60 GHz signals as a function of the heater power.

[1] B. Kuhlow, G. Przyrembel, E. Ehlers, R. Ziegler, G. Großkopf, R. Eggemann and D. Rohde, "Silica based optical beam former in a 60 GHz radio-over-fibre system", Proc. Seminar on Broadband Communications, Zürich 2002.

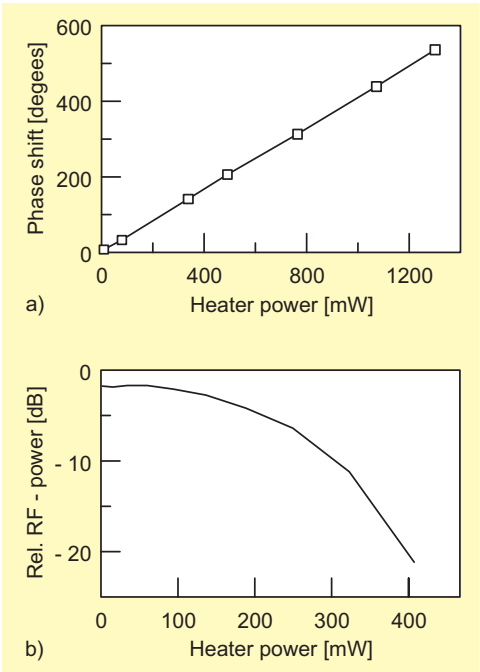


Fig. 2: Typical measured phase shift (a) and attenuation (b) at 60 GHz in one channel of a 4-channel OBFN

Berndt Kuhlow (kuhlow@hhi.de)

Peak Value Estimation for Multi-Carrier Signals

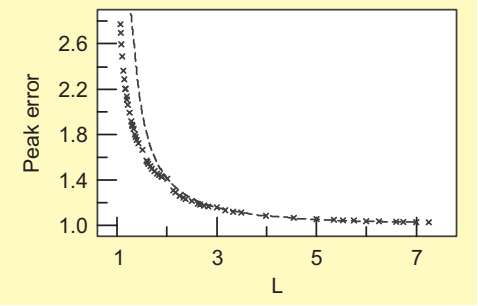
Orthogonal frequency-division multiplexing (OFDM) communication systems enjoy a well-established history of 30 years of research and development. A major barrier for their widespread acceptance in low-cost applications is the high peak-to-average power ratio (PAPR) of the transmitted signals.

The main disadvantage of OFDM transmission is its high peak-to-average power ratio (PAPR). If the peak power is limited by a regulatory body, then the average power allowed under OFDM is reduced compared to constant power modulation schemes. Also, the transmit power amplifier must operate in a power-inefficient region. On the other hand limiting the output back-off causes clipping of the transmitted signals, leading to spectral re-growth and increased bit error rates.

The clipping rate depends on the statistical distribution of the PAPR of the OFDM signals. However, the distribution of the PAPR is difficult to analyse, and so far an accurate estimation is still not possible. Upper bounds were derived in [1] that can be applied in regions where simulations are time consuming.

Another key parameter is the highest possible PAPR, referred to as the maximum PAPR. A method for computing the maximum PAPR for coded OFDM systems was presented in [3]. It is clear that for standard subcarrier modulation methods, such as BPSK, the square root of the maximum PAPR grows linearly with the number of subcarriers. However, it was shown in [1] that the probability that the maximum PAPR is attained is extremely low. It was further shown that the PAPR of an OFDM signal is with very high probability of order N log(N) for large subcarrier numbers N. Therefore the PAPR of a system should be compared with N log(N) rather than N. If the bounds in [1] are applied, an effective PAPR can be found by assuming that the probability of an OFDM signal with this PAPR is negligible in practice.

A fundamental result about the estimation of the peak value of OFDM signals from the samples of complex band-limited signals was derived in this work [2]. The major result is that, as long as oversampling is applied, the peak values of a band-limited signal and its samples differ by a factor that is upper bounded by a trigonometric expression (see the figure). Moreover, this bound is sharp for all practical rates.



Upper bound and computed values of the difference of the peak values of an OFDM signal and its samples, as a function of the oversampling factor L

These results can be used to improve an interesting approach for lowering the maximum PAPR of codes [3]. Future work will further investigate the triple code rate, minimum distance and PAPR of codes.

This work was supported by the Federal Ministry of Education and Research under grant FK 01 BU150.

[1] H. Boche and G. Wunder, "On the PAPR problem in OFDM systems", 39th Annual Allerton Conference on Communication, Control, and Computing, October, 2001.

[2] H. Boche and G. Wunder, "Über eine Verallgemeinerung eines Resultats über trigonometrische Polynome auf allgemeine bandbegrenzte Funktionen", Zeitschrift für angewandte Mathematik und Mechanik, March 2002.

[3] G. Wunder and H. Boche, "A baseband model for reducing the PAPR in OFDM systems", 4th ITG Conf. on Source and Channel Coding, Berlin, January 2002.

Gerhard Wunder (wunder@hhi.de)

Channel Estimation for OFDM MIMO Systems

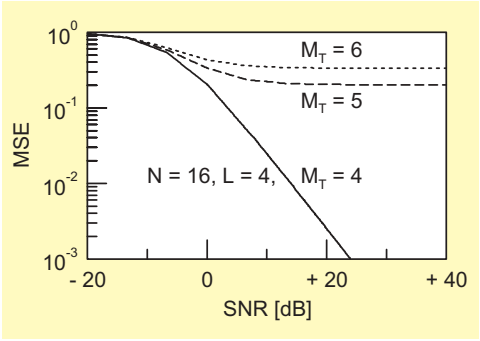
The combination of orthogonal frequency division multiplexing (OFDM) and multiple antennas is a promising candidate for future wireless systems. The capacity, channel estimation schemes and space-frequency codes for such systems are investigated in this work.

It has recently been shown that OFDM MIMO (Multiple Input Multiple Output) systems can increase the capacity of wireless systems to tremendous values. However, a major obstacle to the practical achievement of this capacity is that the radio channel must be perfectly known at the receiver, which is generally impossible. Moreover, taking into account that future wireless systems are expected to operate in highly mobile environments, channel estimation can take a significant part of the communication time, and the system performance will strongly depend on the quality of the estimation schemes.

For convenience, the quality of channel estimation schemes is measured in terms of the mean-squared error (MSE) between the real and the estimated channel coefficients. The MSE measure also permits simple computations to estimate the impact of imperfect channel estimation on the capacity.

Clearly, the choice of the channel estimation scheme is crucial for the system performance, and various schemes have been proposed in the literature. In [1] a pilot signal estimation scheme was proposed in which known OFDM symbols are periodically inserted into the data stream from each transmit antenna, so that the multipath channel coefficients from each transmit antenna to each receive antenna can be estimated within one OFDM symbol interval. In this scheme the MSE depends on the number of subcarriers, representing the degrees of freedom in the system, the number of transmit antennas, the channel delay profiles, and of course, most importantly, the pilot signals themselves. It was shown in [1] that, if the number of subcarriers is larger than the delay spread (maximum number of taps over all channel impulse responses) multiplied by the number of transmit antennas, then a very efficient pilot signal design is possible. Additionally, the pilot signals have a very low crest-factor.

In [1] a broadband scenario with low mobility was assumed. However, in scenarios with high mobility, the number of subcarriers, i.e. the degrees of freedom, typically cannot be made arbitrarily large, as this number is limited by the coherence time of the channel. Therefore, for future system design the case where the number of antennas times the delay spread exceeds the number of subcarriers has also been considered. A lower bound on the MSE for channels with equal power delay profile was derived, and is shown in the figure. This upper bound serves as a fundamental limit with respect to the system performance and is particular suited for trading off MSE for throughput. Moreover, for some special cases also the optimal pilot signals were designed.



Lower bound of MSE, with parameters number of subcarriers N, channel delay spread L and number of transmit antennas M

Future work will include the design of space-frequency codes and the investigation of the performance of OFDM MIMO systems in high mobility environments.

This work was supported by the Federal Ministry of Education and Research under grant FK 01 BU150.

[1] G. Wunder and H. Boche, “Performance bounds and optimal pilot signals in OFDM MIMO systems”, Aachen Symposium on Signal Theory, September 2001.

Gerhard Wunder (wunder@hhi.de)

BER for MIMO Systems in Rayleigh and Rician Channels

Multiple Input Multiple Output (MIMO) systems, which are under intensive research at present, are discussed, with particular attention to the bit error rates (BER) that can be achieved in indoor scenarios. We focus on the influences on the BER of antenna diversity, a line of sight (LOS) component, and channel estimation errors. Our simulation environment allows us to determine the channel estimation accuracy required to achieve the desired BER performance under certain constraints.

Efficient use of bandwidth is needed for the extremely fast growing wireless communication market. The approach with the highest spectral efficiency for wireless indoor communication is to use transmit (Tx) and receive (Rx) antenna arrays to exploit the MIMO channel.

The achievable BER is an important criterion for the design of experimental MIMO systems. We investigate the BER performance for MIMO systems and how it is influenced by antenna diversity, a LOS component, and channel estimation errors.

How to achieve maximum capacity in the MIMO channel is well understood, but further investigation is needed for the more practical aspect of implementation. The MIMO channel capacity with no channel information at the Tx is given by

$$C = \sum_{k=1}^{Min(n_r, m_t)} \log_2\left(1 + \frac{P_k}{\sigma_n^2} \cdot \lambda_k^2\right)$$

where P_k/σ^2_k is the signal-to-noise-ratio (SNR) of the k-th sub-channel and λ_k is the k-th singular value of the MIMO channel matrix [1]. Each singular value (SV) determines the quality of one of the parallel sub-channels, and therefore its capacity and BER.

Figure 1 shows the statistical distribution of the singular values for 8 Tx and 8 or 12 Rx antennas. Additional antennas at the Rx increase all singular values, which results in only a small increase of the total capacity but gives a significant improvement of the BER performance because the smallest SVs are increased, and these belong to the sub-channels with the worst SNRs and cause most of the bit errors.

A LOS component (worst case = far field approximation) simply increases the biggest SV, which gives little gain in capacity, and no BER improvement is observed.

It was shown that channel estimation errors with a correlation-based measurement in a separate time slot have an effect similar to additional noise power, and in the worst case a power penalty of 3 dB applies.

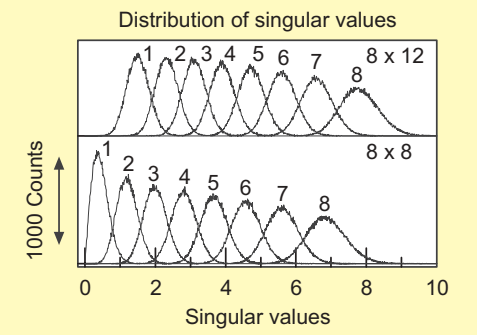


Fig. 1:
Distributions of the singular values for a MIMO system using 8 Tx and 8 or 12 Rx antennas

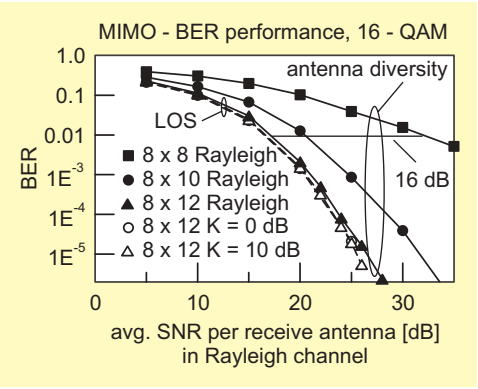


Fig. 2:
BER with antenna diversity as a parameter, including the case of a LOS component

From our investigations we conclude that the BER of a practical MIMO system benefits strongly from antenna diversity, although the capacity is not significantly improved. A LOS component is of little importance for the BER performance, but increases the capacity, especially in the low SNR region.

This work was supported by the Federal Ministry of Education and Research under grant 01 BU 150.

[1] G.J. Foschini, "Layered space-time architecture for wireless communication in a fading environment when using multiple antennas", Bell Lab. Tech. J., 1996, 1, (2), pp. 41-59.

[2] T. Haustein et al., "Bit error rates for a MIMO system in Rayleigh and Rician channels", Proc. VTC-Fall '01, Atlantic City, October 2001, pp. 1984-1987.

Thomas Haustein (haustein@hhi.de)

Eigenvalue and Inverse Eigenvalue Statistics for Rayleigh and Rician MIMO Channels

The probability density functions for the eigenvalues and inverse eigenvalues of Rayleigh and Rician MIMO channels are derived, as well as useful formulas for the moments of these distributions. Examples of the use of these results for MIMO system design are given.

Multiple antennas can be used at the transmitter and receiver to create a multiple-input multiple-output (MIMO) channel to enhance the performance and capacity of a wireless communication system. It is necessary to know the statistical properties of the MIMO channels if the promised capacity and performance gain are to be achieved. At least the first and second moments of the inverse eigenvalue distributions of the Rayleigh and Rician MIMO channel matrices must be known, especially for the analysis of the bit error performance and to estimate the required transmit power in water-filling or channel-inversion transmission schemes.

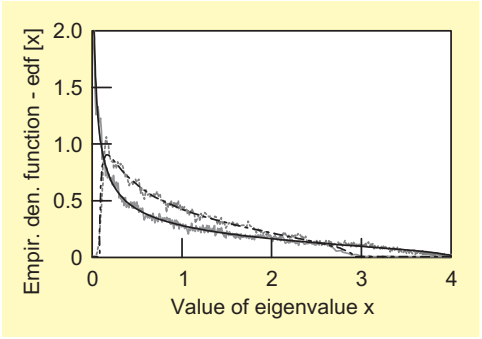


Fig. 1: Simulated and theoretical distributions of the eigenvalues of the 8 x 8 (solid) and 8 x 16 (dashed) Rayleigh MIMO channel

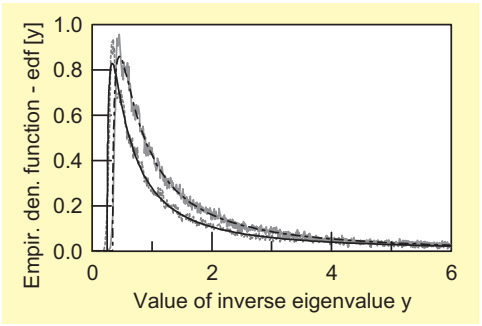


Fig. 2: Simulated and theoretical distributions of the inverse eigenvalues of the 8 x 8 (solid) and 8 x 16 (dashed) Rayleigh MIMO channel

The Rayleigh MIMO channel models the case of rich multipath propagation between the receive and transmit antennas without a line-of-sight component, whereas the Rician MIMO channel contains a line-of-sight component. In Rayleigh MIMO channels the channel matrix consists of independently and identically distributed zero-mean complex Gaussian random variables, whereas in Rician MIMO channels the channel matrix entries have non-zero means. In indoor environments these channel models fit the measured channel data well.

Tools for computing the empirical distribution functions of the eigenvalues are reviewed in [1], and new results for the inverse eigenvalues of Rayleigh and Rician MIMO channel matrices using the Stieltjes transform are presented. A simple method for calculating the moments of the inverse eigenvalues in the transform domain yields analytical formulas for the means and variances of the inverse eigenvalues.

The theory also yields closed form expressions for the empirical distribution functions of the eigenvalues and inverse eigenvalues of these random matrices. In figure 1 the simulated and empirical eigenvalue distribution functions are shown. In figure 2 the simulated data are compared with the theoretical inverse eigenvalue distributions. The theory fits the simulated data well.

It is worth mentioning that the means of the inverse eigenvalues of quadratic MIMO systems do not exist. The average noise gain in MIMO zero-forcing receivers can easily be reduced by increasing the number of receive antennas, and system designers can decide in advance what minimum receive-to-transmit antenna number ratio is necessary to achieve a given error performance.

[1] E. Jorswieck, G. Wunder, V. Jungnickel and T. Haustein, "Eigenvalue and inverse eigenvalue statistics for Rayleigh and Rician MIMO channels", IEE Workshop on MIMO Systems, London, December 2001.

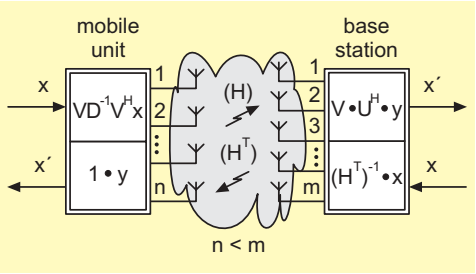
Eduard Jorswieck (jorswieck@hhi.de)

A MIMO WLAN based on Linear Channel Inversion

A Multiple-Input Multiple-Output (MIMO) system is proposed that uses radio channel reciprocity and linear channel inversion. This scheme is especially attractive for broadband indoor wireless local area network (WLAN) applications, since the required signal processing schemes are inherently fast and of low complexity.

Multiple-Input Multiple-Output (MIMO) transmission is very attractive for an indoor wireless local area network (WLAN), since it exploits the enormous capacity hidden in the rich scattering multi-path propagation that is typical of indoor environments. But relatively complex and powerful signal processing is needed to implement the popular BLAST algorithms [1] at the high data rates typical in WLAN applications.

Signal processing before data transmission is possible if channel state information (CSI) is available at the transmitter (Tx). Because the radio channel is reciprocal, CSI can be made available at the Tx by taking it from the CSI used for detection of the received signal. Linear Channel Inversion (LCI) is a simple processing scheme based on CSI at the Tx. In the down-link at the Tx, data are multiplied by the pseudo-inverse of the transposed channel matrix H^T, while slightly more complex processing is needed in the up-link (see Fig. 1).



LCI results in a statistical distribution of the Tx power which depends on H. This distribution can be described in terms of the inverse eigenvalues of HH^H, where H^H is the Hermitian transpose of H. For the Rayleigh fading channel, an analytical expression for the empirical density function of the inverse eigenvalues can be found, from which the average Tx power can be obtained (see the preceding contribution). As a general result, at least one extra antenna is needed on one side of the link. The noise gain is isotropic with LCI, and the bit-error performance is similar to that of the additive white Gaussian noise (AWGN) channel. Compared to the AWGN channel the BER curve of LCI is shifted towards higher Tx/noise power values by a factor n/(n-m), due to signal processing at the Tx. The figures n and m are the numbers of antennas at the mobile unit and at the base station respectively. For small bit error rates, the performance in terms of Tx power is significantly better than with Zero Forcing (ZF). In the case of many parallel data streams VBLAST performs even better (see Fig. 2), but the complexity of the required signal processing increases significantly. LCI is more sensitive than VBLAST to channel estimation errors. Fortunately this is unproblematic at high data rates, where long pilot sequences can be used without losing too much time for channel estimation.

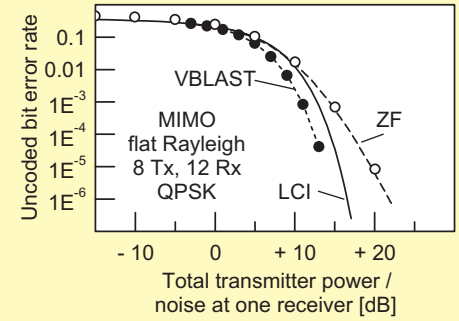


Fig. 2:
Bit error rates as a function of the transmitter power with perfect channel estimation. Dots are the simulation results, while full and dashed lines are the theoretical curves for zero forcing (ZF) and LCI. (The dashed line for VBLAST is only there as a guide for the eye.)

Fig. 1:
Principle of linear channel inversion (LCI) for MIMO transmission. The matrices U, D and V refer to the singular value decomposition of $H = UDV^H$.

In conclusion, MIMO with LCI is a promising candidate for WLAN applications. Like VBLAST, LCI offers significantly better performance than ZF. In addition, LCI needs less signal processing than VBLAST when the number of data streams is large.

This work was supported by the Federal Ministry of Education and Research under grant 01 BU 150.

[1] G. D. Golden, G. J. Foschini, R. A. Valenzuela and P. W. Wolniansky, Electronics Letters, 35, 14-15, 1999.

[2] V. Jungnickel, T. Haustein, E. Jorswieck and C. von Helmolt, Proc. IEE Technical Seminar on MIMO Communication Systems, London, 12.12.2001.

Clemens v. Helmolt (helmolt@hhi.de)

On Transmit Diversity with Imperfect Channel State Information

The optimal transmission strategy for a multiple-input single-output wireless communication link is studied for the case in which the receiver has full channel state information and the transmitter knows only the channel covariance matrix.

It is well known that multiple-element antenna arrays can improve the performance of a wireless communication system in a fading environment.

We consider the multiple-input single-output (MISO) single-user case with imperfect channel state information at the transmit array. It has been shown that even partial channel state information at the transmitter (CSIT) can increase the capacity of a MISO system. Recently transmission schemes for optimizing the capacity of MISO mean-feedback and covariance-feedback systems have been derived. It was shown that the optimal capacity can be achieved with Gaussian transmit signals with a particular covariance matrix. Further it has been proved that the optimum transmit covariance matrix has the same eigenvectors as the known channel covariance matrix. The optimum eigenvalues can be computed numerically.

The number of eigenvalues greater than zero corresponds to the number of directions in which the transmit signals are sent. If the number of directions is one, the system performs beamforming. If perfect channel state information is available at the transmitter, or if the signal-to-noise ratio (SNR) is low, beamforming is known to be optimal. For the general case the required number of eigenvalues to achieve maximum capacity is not known a priori, and cannot be easily computed from the channel covariance matrix eigenvalues.

Diversity function as a function of the SNR

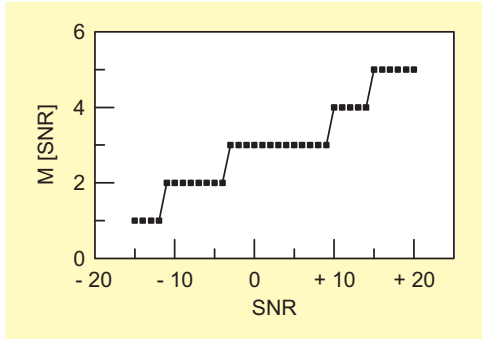
A necessary and sufficient condition for the optimality of beamforming for MISO systems with covariance feedback has been derived in the literature. We extend these results in [1] to the general case with transmission in a specified number of directions.

A necessary and sufficient condition has been derived for the optimum eigenvalues of the transmit covariance matrix of an MISO system with many transmit antennas and one receive antenna, assuming a known channel covariance matrix. A necessary and sufficient condition for achieving maximum capacity when transmitting in a fixed number of directions was also obtained.

With these conditions it is possible to answer the following questions about the system design of MISO systems:

- For a fixed number of transmit antennas and a given channel covariance matrix, what is the required SNR to take advantage of full space diversity?
- Given the channel covariance matrix and the SNR, what is the minimum number of parallel data streams needed to achieve maximum capacity?
- What is the maximum spatial diversity for a fixed channel covariance matrix as a function of the SNR?

These questions can be answered using the new results. For example, in the figure the diversity function is shown as a function of the SNR. The diversity function yields the minimum and maximum required number of directions to achieve capacity given a fixed channel covariance matrix, and hence answers the third question.



Helpful tools for computing the optimum number of transmit antennas and the required SNR to take advantage of full space diversity were derived. These considerations gave insight into the optimum single-user MISO system design. Open questions concern the multi-user case and the MIMO case.

[1] E. Jorswieck and H. Boche, "On transmit diversity with imperfect channel state information", accepted to ICASSP 2002.

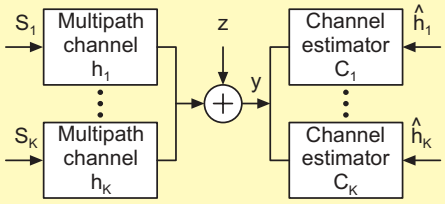
Eduard Jorswieck (jorswieck@hhi.de)

Pilot Signal Design for Multiuser Channel Estimation Systems

We investigated the mean-squared error performance of a pilot-based channel estimation scheme in a code-division-multiple-access (CDMA) multipath environment. We derived the optimum linear estimator in the absence of any prior knowledge and obtained a lower bound for the maximum mean-squared channel estimation error.

Transmission of a pilot signal in wireless systems is a very useful way of obtaining good amplitude and phase estimates of the multipath channel, thereby making possible quasi-optimum coherent reception and weighted combining of multipath components. Pilot-based channel estimation schemes are widely used in the downlinks of wireless communication systems. The much more difficult case of the many-to-one uplink from multiple wireless users to a base station is still the subject of intense research work.

The figure shows the underlying model of a multiuser system under consideration.



Model of a pilot - based channel estimation system with K users.

Here, each user, say user *k*, transmits a distinct *N*-periodic pilot signal S_k to a common base station, while autonomously operating in an uncorrelated multipath radio environment. The multipath channel is modelled by the vector h_k containing *N* independent identically distributed Gaussian random variables with variance σ_c. The received signal y is disturbed by the zero mean complex Gaussian random vector z with the variance σ. In each period, the channel estimator of the k-th user with impulse response C_k observes *N* samples of the received signal and gives an estimate of the multipath vector h_k. Apart from noise and inter-symbol interference, the channel estimation system must also combat inter-user interference to obtain reliable channel estimates, which is in clear contrast to the downlink scenario. In our analysis we assumed that neither σ_c nor σ are known to the receiver. We used the mean squared estimation error (MSEE) as an optimization criterion.

For a given set of pilot signals, it may be easily shown that a bank of inverse filters at the receiver is optimal. However, it turns out that the MSEE still depends on the choice of pilot signals. Assuming a bank of inverse filters, we proved that the MSEE for each user is bounded below by $\sigma_c(K-1)+\sigma$, where the lower bound is attained if and only if each pilot signal is a periodically self-invertible sequence. Since the normalized discrete Fourier transform of such sequences is equal to the complex conjugate of its inverse, a simple bank of matched filters is the optimum channel estimation system if the pilot signals form a set of periodically self-invertible sequences. Thus, a careful choice of pilot signals not only improves the average performance of a channel estimation system but also reduces its complexity. We also showed that a bank of simple matched filters also gives optimal performance if a complementary set of periodic sequences is used.

Periodically self-invertible sequences are rare. In the bipolar case, there is most probably only one such a sequence. In complex spaces, some construction methods are known. In contrast, complementary sets of binary sequences are easy to construct, although these are not as robust as sets of periodically self-invertible sequences.

Model of a pilot-based channel estimation system with K users

These results show that obtaining reliable estimates of multipath components in multiuser systems can be a difficult task. This is especially true for large systems, since the lower performance bound increases linearly with the number of users. Better performance can be obtained if knowledge of the variances is available and utilized at the receiver.

[1] H. Boche and S. Stanczak, "Lower bound on mean squared channel estimation error for multiuser receiver", Proceedings of IEEE International Symposium on Circuits and Systems, Sydney, Australia, 6-9 May, 2001.

Slawomir Stanczak (stanczak@hhi.de)

Sequence Design for Quasi-Synchronous CDMA Systems

We present a unified theory for constructing sets of mutually orthogonal sequences with small aperiodic correlation magnitudes in the vicinity of the zero shift. We also prove some important bounds related to sets of such sequences.

We say that a code-division multiple-access (CDMA) system is quasi-synchronous (QS-CDMA) if the duration of the modulated symbols T is significantly longer than $Ta + Tm$, where Ta is the maximum time dispersion of a multipath channel and Tm denotes the maximum relative time delay resulting from non-perfect synchronization of the spatially separated mobile users. Since coarse synchronization of users can usually be established with a GPS-based common clock, or alternatively, with the aid of higher-layer network protocols, we can assume that $Tm \approx 0$. The parameter Ta varies between about 2 µs and 20 µs, depending on the multipath radio environment. Figure 1 shows a typical configuration of a QS-CDMA transmitter.

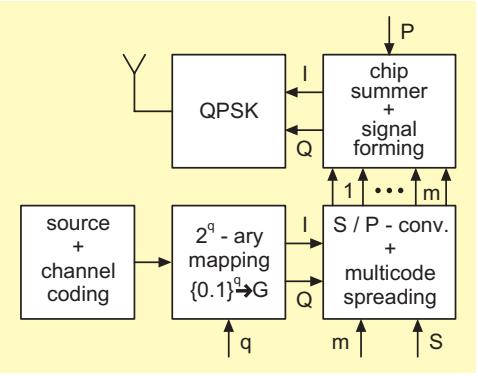


Fig. 1: Typical configuration of a QS-CDMA transmitter

In order to achieve high data rates in QS-CDMA systems, the duration of the encoded binary symbols of length Ts needs to be extended. To this end, we can employ a mapping from a set of binary vectors of length q onto a finite set of complex numbers G of order 2^q and/or a multicode technique that allocates m sequences to each user. The parameters q and m are chosen so that the quantity $d = [NT_a/(q\ m\ T_s)] + 1$ is significantly smaller than the length of the sequences N. A guard interval of length d-1 is also usually inserted between any two consecutive sequences.

All this has tremendous implications on how to design spreading sequences, since we only need to consider aperiodic correlations in the small window $\{-d+1,\ldots, d-1\}$. In particular, to eliminate inter-symbol interference (ISI) and multiple access interference (MAI) completely in QS-CDMA systems, it is sufficient to construct sequences so that all aperiodic autocorrelation sidelobes and cross-correlations are zero within this window. Aperiodic zero-correlation-window (AZCW) sequences have been shown to exist on the complex unit sphere. We proved that the number of AZCW sequences is bounded above by N/d if d divides N, which means that sets of AZCW sequences may be too small for many applications.

To overcome this problem we can consider sets of sequences for which all aperiodic correlation magnitudes within the window (except for the autocorrelation at the origin) do not exceed a certain given small value. We have found an upper bound on the number of such sequences on the complex unit sphere. We also constructed a class of mutually orthogonal sequences for which the maximum aperiodic correlation magnitude in this window is bounded above by $(d-1)/N$, and showed that the use of such sequences in QS-CDMA systems keeps the total interference (ISI+MAI) at a low level. We proved that the interference in a fully loaded system can be expected to be significantly smaller than $2d^2/(3N)$. Figure 2 shows typical aperiodic autocorrelations of binary sequences obtained using our construction procedure.

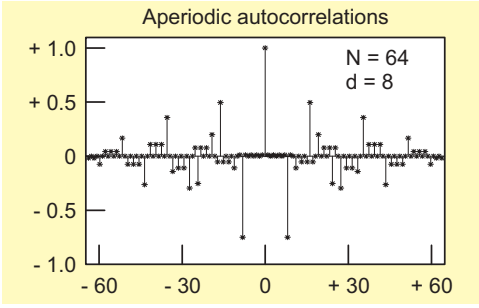


Fig. 2: Aperiodic autocorrelations

[1] S. Stanczak and H. Boche, "Sequences with small aperiodic correlations in the vicinity of the zero shift", to appear in 4th International Conference on Source and Channel Coding, Berlin, 28-30 January, 2002.

Slawomir Stanczak (stanczak@hhi.de)

Resource Allocation in Asynchronous CDMA Systems

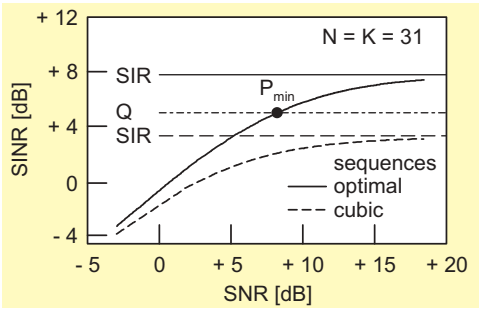
We solve the problem of admissibility in an asynchronous code-division-multiple-access (A-CDMA) system, assuming that all users have the same quality-of-service requirements, expressed as the signal-to-interference+noise ratio (SINR).

Designers of future wireless communications systems will be confronted with the problem of how to use scarce resources such as power and bandwidth in order to satisfy stringent quality-of-service requirements.

The signal-to-interference+noise ratio (SINR) is a useful measure of the quality of a multiuser receiver, particularly when it is used in conjunction with error-control decoders. SINR is a soft-decision variable that reflects the reliability of decisions. Roughly speaking, the larger the SINR is, the more reliable the decisions are, and hence there is higher quality-of-service for the users. Thus, to guarantee a certain quality-of-service for the users, we demand that $Q \leq SINR_k$ for each k, where $SINR_k$ is the SINR for the k-th user and Q is a given real number, called the SINR requirement. We say that a set of users is admissible in a CDMA system if we can assign sequences to the users and control their power so that each user meets the SINR requirement Q.

The problem of admissibility of the users in a synchronous CDMA (S-CDMA) system was completely solved in [1]. However, since the simplistic setting of perfect symbol synchronization rarely holds in practice, there is a strong need to investigate asynchronous CDMA (A-CDMA) systems. We therefore dropped the demand for perfect symbol synchronization and considered a chip-synchronous A-CDMA system embedded in zero-mean additive Gaussian noise with variance σ. Such a CDMA system is obtained if the relative time offsets that model the lack of synchronization between the users at the receiver are assumed to be discrete random variables uniformly distributed on the symbol interval.

Let S be a set of K sequences assigned to the users and $P = (p_1,\ldots, p_K)$ be a set of powers at which users are received. To show when exactly K users are admissible in a CDMA system with processing gain N, it is sufficient to identify a pair (P, S), called an optimal allocation, for which the minimum SINR is as large as possible. We solved this max-min optimization problem for $N \leq K$ assuming that S forms a set of polyphase sequences. Such sequences are widely used in practical systems, since they can be transformed easily into a carrier pulse train with a modulated phase. The optimum power allocation is $p = p_1 = \ldots = p_K$, where p is subject to a given power constraint, and the optimum sequence allocation is a complementary set of sequences in which each member has the minimum merit factor for its aperiodic autocorrelations. We constructed such a set of sequences for $N \leq K$.



Minimum SINR as a function of SNR for optimal and cubic phase sequences

The figure depicts the minimum SINR as a function of the signal-to-noise ratio ($SNR = p/\sigma$) for both optimal sequences and the so-called cubic sequences, which are known to have favourable periodic correlation properties. As seen in the figure, if optimal sequences are allocated, users meet the SINR requirement of 5 dB at a SNR of about 8.2 dB. P_{min} in the figure is the minimum power for which this is still true. In the case of cubic sequences, the SINR requirement cannot be satisfied for all users.

[1] P. Viswanath, V. Anantharam, D. Tse, "Optimal sequences, power control, and user capacity of synchronous CDMA systems with linear MMSE multiuser receivers", IEEE Trans. on Inform. Theory, vol. 45, no. 6. September 1999.

[2] S. Stanczak and H. Boche, "On resource allocation in asynchronous CDMA channels", to appear in Proc. of the 2002 IEEE International Symposium on Information Theory (ISIT 2002), Lausanne, Switzerland, June 30-July 5, 2002.

Slawomir Stanczak (stanczak@hhi.de)

Experimental Smart Antenna System for UMTS

Smart antenna techniques are proposed to enhance the system capacity of future 3G mobile communication systems. Smart antenna design involves various fields of electrical engineering. To perform experiments in the fields of antenna array design, RF hardware design, array calibration techniques and array signal processing, an experimental smart antenna system has been developed.

The system consists of an antenna array with RF receiver front end (Fig. 1), a digital array receiver (Fig. 2), a personal computer (PC) for controlling the measurements and performing signal processing, and three test transmitters with single antennas. The antenna array represents the base station receiver antenna and the test transmitters play the role of mobile stations in the uplink mode.

Fig. 2: Digital array receiver and signal processing PC

Fig. 1: Experimental 2 GHz linear microstrip antenna array

The system operates in the UMTS radio frequency range from 1.9 GHz to 2.2 GHz with a signal bandwidth of 5.0 MHz. For test purposes UTRA-TDD signals have been implemented at the test transmitters.

The receiver system consists of parallel RF/IF/ADC hardware. All output signals from the receiver antenna array are simultaneously converted into complex digital baseband signals. Signal combining is not performed in the RF or IF domain, so that a wide range of digital signal processing algorithms can be used instead.

The experimental system uses offline signal processing with a PC instead of a real-time signal processing unit. The digitalized received signals are stored in memory devices before performing signal processing.

One of the main advantages of this concept for an experimental system is that we can use algorithms with large computational effort because there is no strict time limitation for the processing. Furthermore, a variety of signal processing algorithms can be applied to the same measured data, which is another advantage for evaluation purposes.

To perform the measurements, the test transmitters and the receiver antenna array are placed in an anechoic measurement chamber. Various measurement scenarios can be arranged by changing the positions, the power levels and the test signals of the test transmitters. Furthermore, the angular position of the receiver antenna array can be varied with a remote controlled positioner device.

To simulate multipath and fading effects, which are typical for wave propagation in mobile radio systems, reflecting and moving devices can be placed in the measurement chamber. Scenarios with a larger numbers of active mobile stations can be simulated by superposition of the received signals in the digital domain.

A software library containing device drivers, signal processing algorithms and control procedures has been developed to operate the system. To extend the system capabilities to downlink experiments, an array signal generator and an array transmitter front end will be developed in future.

This work is supported by the Gesellschaft von Freunden des Heinrich-Hertz-Instituts e.V.

[1] A. Kortke and G. Mönich, “Antenna array calibration algorithms”, MICRO.tec 2000, VDE World Microtechnologies Congress, Hannover, September 2000, vol. 2, pp. 193-198.

Andreas Kortke (kortke@hhi.de)

Optimal Multiuser Downlink Beamforming

We address the problem of joint downlink beamforming and power control in a cellular wireless system, assuming that an antenna array is employed at the base station and that each user is equipped with a single antenna element. The goal is to minimize the transmitted power while satisfying individual link capacity requirements for all users. The HHI has developed a computationally efficient optimization scheme for solving this nonlinear multi-user problem.

The downlink of future multimedia-type wireless systems will exhibit very large peak-to-average capacity demands, which can only be fulfilled by adaptive transmission strategies that are optimally matched to the actual channel states. Significant gains in spectral efficiency can be achieved by exploiting the spatial diversity and processing gain offered by the multipath channel. This requires the employment of antenna arrays at the base station and/or the hand-held device. In a typical wireless system, however, the size and energy storing capability of the hand-held preclude the use of arrays at that end. Recent results show that in this case beamforming at the base station is close to the optimal transmission strategy.

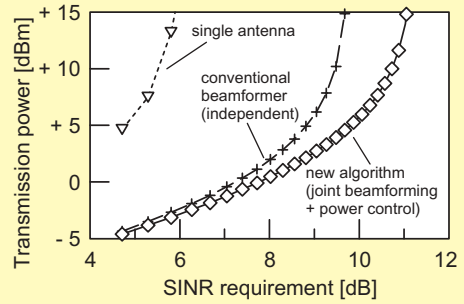
Classical results on beamforming focus on single-user systems. Typical wireless systems, however, are limited by severe co-channel interference. Thus, high peak data rates can only be achieved by jointly optimizing the beamforming weights of all users, together with dynamic resource management. In a large system there is likely to be a set of users with large separations in terms of azimuth angle at any time. By choosing the users with the best channel characteristics and azimuth distributions, large capacity gains can be expected.

However, the actual link capacity of a particular user depends strongly on the beamforming weights. The optimum weights must be found by jointly optimizing the communication links for all users.

The optimization goal is to guarantee each user a certain data rate, subject to strict delay constraints. This leads to the problem of jointly balancing the signal-to-interference-plus-noise-ratios (SINRs) – an individual SINR must be achieved for each user. If a solution to this non-linear optimization problem exists, additional degrees of freedom can be used to minimize the total transmission power, thereby reducing the amount of co-channel interference received by neighbouring cells. This strategy not only increases the overall system capacity, but also improves the power efficiency.

The HHI has developed a new iterative algorithm [1] that solves this problem with minimal computational burden. The proposed algorithm always converges to the global optimum within 3-4 iteration steps. Moreover, it is able to detect infeasible scenarios, in which the required SINR levels cannot be achieved for the given power threshold. The algorithm provides a measure for the achievable SINR margin, so that it can be used very efficiently for resource management.

Among a set of active users, the algorithm finds those that are most favourable for transmission. Then, it determines the beamforming weights that minimize the total transmission power while satisfying individual SINR requirements.



Power minimization capability of the new algorithm

The trade-off between the transmission power and the achievable SINR margin for different beamforming techniques is compared in the figure. Conventional techniques are clearly outperformed by the new optimization scheme.

[1] M. Schubert and H. Boche, "Multi-antenna downlink transmission with individual SINR receiver constraints for cellular wireless systems", Proc. ITG Conference on Source and Channel Coding, Berlin, Jan. 2002.

Martin Schubert (schubert@hhi.de)

Joint Uplink/Downlink Beamforming Optimization

We address the problem of multi-user signal-to-interference ratio (SIR) balancing in a cellular wireless system in which an antenna array is employed at the base station and each mobile is equipped with a single antenna. In this work it is shown that there is an interesting duality between the uplink and downlink beamforming problems. We use this duality to develop a rapidly converging algorithm that always converges to the optimum multi-user beamforming solution, for both uplink and downlink. A convergence analysis and proof of optimality are provided in [1].

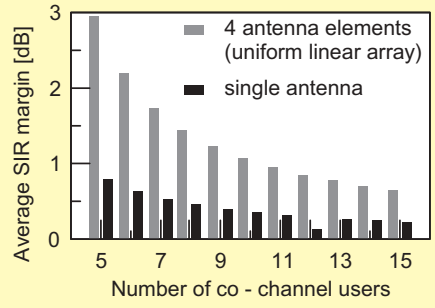
Future cellular or personal communication systems must be able to achieve high peak data rates with low-complexity mobile terminals. This challenging goal can only be achieved by employing cell-site antenna arrays that are able to exploit the spatial diversity and processing gain offered by the wireless channel. In this context, beamforming is a promising strategy for both transmission and reception. By pointing a beam towards the desired user, co-channel interference can be significantly reduced. This results in improved signal-to-interference ratios (SIRs). The resulting gains can be traded for increased capacity or reduced transmission power.

Most studies on beamforming so far consider the uplink multi-access channel, where the users are coupled by the transmission powers. Once the optimum power levels are determined, the optimum beamforming filters can be found by solving a set of independent eigenvalue problems [1].

In the downlink, the data are transmitted over a broadcast channel and the spatial processing must be carried out prior to transmission. As for the uplink, all users are coupled by crosstalk. This crosstalk, however, is not determined only by the transmission powers, but also by the choices of the individual beamforming filters. This makes the downlink problem more complicated than the uplink problem. In particular, the downlink beamformers cannot be optimized by simple eigenvalue decomposition, as was the case for the uplink.

The HHI has shown [1] that there is an interesting duality between the uplink and downlink beamforming problems. The beamforming vectors that optimally balance the signal-to-interference ratios (SIR) in the uplink are also optimal in the downlink. This, however, does not hold for the transmission powers. Whereas the optimum uplink powers are given by the dominant right-hand eigenvector of the system coupling matrix, the downlink powers are obtained from the dominant left-hand eigenvector. Consequently, the complicated downlink SIR balancing problem, which was first addressed in [2] and later by many authors, can be efficiently solved by considering the uplink problem instead.

This downlink/uplink duality has been used to develop a new rapidly convergent optimization scheme [1]. By alternately optimizing beamforming weights and transmission powers, we obtain an iteration sequence that monotonically and rapidly converges to the global optimum of the joint SIR balancing problem [2], regardless of the chosen initialization.



Average SIR improvement for various numbers of co-channel users uniformly distributed in a 120° cell sector

Numerical simulations show that the new algorithm typically converges within 3-4 iteration steps. Thus it is suited for real-time applications in future wireless systems. The simulation results in the figure show that large capacity gains can be expected compared to single antenna transmission. These gains can be traded for increased user density or decreased transmission power.

[1] M. Schubert and H. Boche, “A unifying theory for uplink and downlink multi-user beamforming”, Proc. International Zürich Seminar, 2002.

[2] D. Gerlach and A. Paulraj, “Base station transmitting antenna arrays for multipath environments”, Signal Processing (Elsevier Science), vol. 54, pp. 59-73, 1996.

Martin Schubert (schubert@hhi.de)

60 GHz Optically Controlled Maximum Directivity Beamformer

A 60 GHz patch array antenna that is to be used as a smart antenna in a broadband mobile communication system is described. The antenna field pattern was synthesized using the maximum directivity beamforming algorithm. In the experiments the 60 GHz signals were generated by optically heterodyning the waves from two laser diodes, and the look direction of the 1x4 antenna was steered by an optical beamformer.

The use of space division multiple access (SDMA) in the 60 GHz frequency range is becoming more and more interesting for mobile communications. An important building block for a mobile system is the phased array antenna. By using SDMA, the mobile terminal considered here can be connected to the base station via an optimum radio link, at the same time suppressing the signals from the other terminals and minimizing emission into the neighbouring environment.

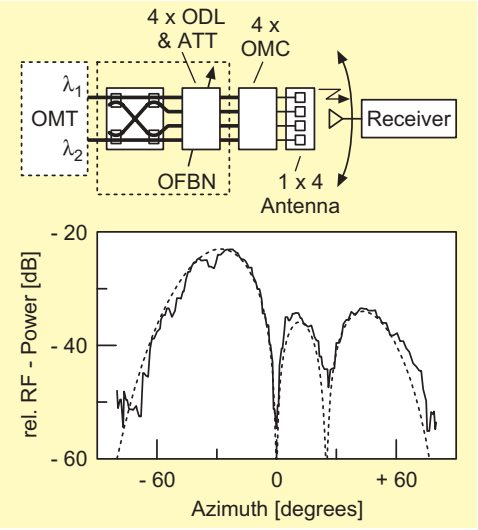
Constrained beamforming is usually achieved by amplitude and phase control of the individual millimetre-wave signals feeding the array antenna elements, which is difficult at 60 GHz. Thus beamforming by optical means is an interesting alternative solution. In an optical beamformer the phases and amplitudes of a number of optical signals are controlled individually, and hence the millimetre-wave signals feeding the array antenna are also controlled.

Beamforming is achieved by a complex weighting of the individual antenna signals. The Maximum Directivity (MD) beamformer algorithm [1] enables us to steer both a main beam and a number of nulls in the radiation characteristic, and achieves a beam with the highest possible directivity. The number of nulls can vary from 0 to M-1, where M is the number of antenna elements. In the case of four antenna elements we can specify one look direction ϑ_{LD} and K null directions ϑ_{OK}, $0 \le k \le K$, with K between 0 and 3. The choice $K = 3$ gives a full rank 4 x 4 linear equation system:

$$\begin{pmatrix} G(\vartheta_{LD}) \\ G(\vartheta_0) \\ \cdot \\ \cdot \\ G(\vartheta_{0K}) \end{pmatrix} = \begin{pmatrix} g_1(\vartheta_{LD}) & g_2(\vartheta_{LD}) & g_3(\vartheta_{LD}) & g_4(\vartheta_{LD}) \\ g_1(\vartheta_0) & g_2(\vartheta_0) & g_3(\vartheta_0) & g_4(\vartheta_0) \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ g_1(\vartheta_{0K}) & g_2(\vartheta_{0K}) & g_3(\vartheta_{0K}) & g_4(\vartheta_{0K}) \end{pmatrix} \begin{pmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \end{pmatrix}^* = \begin{pmatrix} 1 \\ 0 \\ \cdot \\ \cdot \\ 0 \end{pmatrix}$$

where ϑ is the angular direction, w_m is the weight and $g_m(\vartheta)$ is the radiation characteristic of array element m. The four individual radiation characteristics g_m are obtained from simulations of the single antenna element and the complete array structure. These are inserted into the equation system to calculate the antenna weights w_m, after which the field patterns for given look directions are calculated.

An experimental 1 x 4 patch array antenna was developed with $\lambda/2$ spaced antenna elements (size 1 x 1.2 mm). It was tested in a 60 GHz system. The millimetre-wave signals were generated by heterodyning the waves $\lambda 1$ and $\lambda 2$ from an optical millimetre-wave transmitter (OMT), whose optical signals were distributed to four optic/millimetre-wave converters (OMCs) for opto-electronic conversion. Each OMC was connected to one of the antenna elements. Beamforming was performed by tunable optical delay lines and attenuators (OFBN) preceding the OMCs. Figure 1 shows the calculated and measured field patterns at a look direction of –30° with zeros at 0°, 27°, and –70°.



Experimental setup, together with the calculated (dashed) and measured (full) field distributions of the 1 x 4 patch array antenna at 60 GHz in the –30° look direction

[1] T. Kuhwald, H. Boche and M. Bronzel, "A new optimum constrained beamforming-algorithm for future mobile communication systems based on CDMA", Proc. ACTS Mobile Communications Summit '99, Sorrento, Italy, pp. 963-968, June 1999

Gerd Grosskopf (grosskopf@hhi.de)

Silica-Based Beamformer in a 60 GHz Radio-Over-Fibre System

First results with a novel silica-based optical beamformer intended for use in smart antenna environments are reported. The device was tested in an experimental 60 GHz transmission system using optical millimetre-wave generation and a 1x4 phased array antenna.

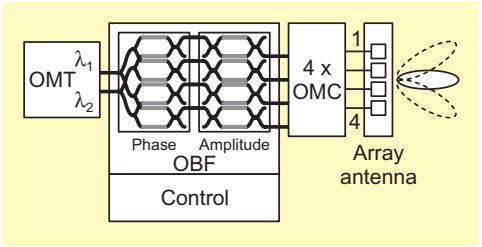


Fig. 1: Experimental setup for optical beamforming and millimetre-wave generation. OMT: optical millimetre-wave transmitter, OBF: optical beamformer, OMC: optic-millimetre-wave converter.

The 60 GHz frequency range and space division multiple access operation (SDMA) will be important in future broadband mobile communication systems. Optical millimetre-wave techniques offer interesting solutions to the problems of such systems. On the one hand these techniques allow the antenna characteristics to be determined by a single opto-electronic integrated circuit (OEIC), while on the other hand millimetre-wave signals with excellent properties can be generated and easily distributed via optical fibres to the base station antennas.

The millimetre-wave signals are obtained by heterodyning two optical waves with a frequency spacing equal to the desired millimetre-wave frequency [1]. These waves are emitted by an optical millimetre-wave transmitter (OMT)(Fig. 1). The beamforming OEIC is realised in silica technology (OBF). To achieve beamforming, the amplitudes and phases of the millimetre-wave signals feeding the array antenna must be individually controlled. Thus the two input waves are each split into a number of paths equal to the number of array antenna elements. A thermo-optic effect is used to adjust the phases, which are controlled by heaters on top of the embedded optical waveguides. The amplitudes are controlled by Mach Zehnder (MZ) structures, also varied by heaters. The advantage of this method is that, for a desired phase shift of the millimetre-wave signal, the phase of only one of the optical waves has to be shifted by the same amount in the optical domain. Finally the optical waves are combined in pairs and coupled to the optic/millimetre-wave converters (OMC) for opto-electronic conversion.

The RF properties of the phase section of the 4-channel OBF were measured using a 1 x 4 phased array antenna. The relative phases of the four 60 GHz signals were adjusted by setting the OBF heater powers to give the desired antenna look direction (Fig. 2). The amplitudes were set to a constant value by fibre-based optical attenuators (these will later be replaced by a 4-channel silica-based attenuator that was recently developed). Constrained beamforming is possible with the completed device [2], i.e. an optimum wireless connection to a desired mobile receiver can be established with negligible extraneous radiation to other terminals and into the environment.

[1] G. Grosskopf, R. Eggemann, D. Rohde and M.S. Choi, “155 Mbit/s data trans-mission at 60 GHz using a 1x4 patch array antenna with variable optical delay lines”, IEEE Intern. Microwave Symp. 2001, Phoenix, USA, pp. 1821-1824.

[2] T. Kuhwald, H. Boche and M. Bronzel, “A new optimum constrained beam-forming-algorithm for future mobile communication systems based on CDMA”, Proc. ACTS Mobile Commun. Summit '99, Sorrento, Italy, pp. 963-968, June 1999.

Gerd Grosskopf (grosskopf@hhi.de)

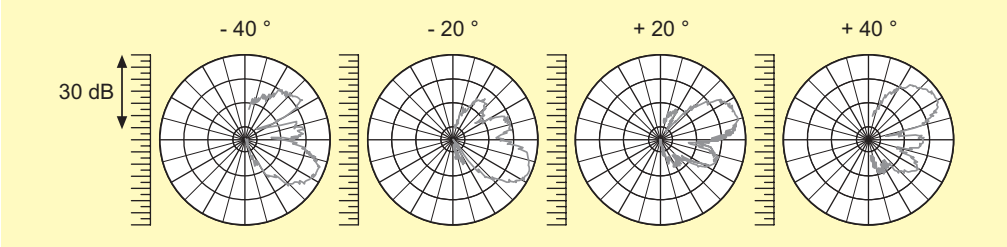


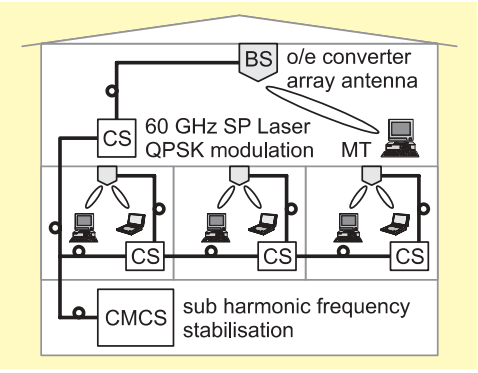
Fig. 2: Measured far-field patterns in the H-plane of the 1x4 phased array antenna at 60.8 GHz in different look directions

60 GHz Microwave Broadband Wireless Access Demonstrator for the Next-Generation Mobile Internet

A novel demonstrator with error-free operation for 155 Mb/s wireless access to mobile stations is presented. Key elements are steered antennas with optical beamforming and a remotely controlled self-pulsating laser used as a microwave source at 60 GHz.

The convergence of the internet and mobile access creates demands for broadband wireless interconnections. Hybrid-fibre-radio (HFR) systems at 60 GHz are of special interest for this application [1]. A complete proposed indoor system with picocellular structure, shown in Fig. 1, consists of four building blocks: a central master control station (CMCS), a number of control stations (CS), each of which supports several base stations (BS), and the mobile terminals (MT). The CMCS, CS and BS are connected by optical fibres.

Steered phased array antennas are an important building block in the BS. They connect the selected MTs and minimise the emission of radiation into the environment. The second advantage of the demonstrator is the cost-effective realisation of the BSs, which is achieved by centralised microwave signal generation using an optical reference source in the CMCS to control 60 GHz optical sources in the different CSs. Their output signals are heterodyned at optic/microwave converters (OMCs) in the numerous BSs.



The 60 GHz source in the CS is a self-pulsating laser (SPL) comprising two active distributed feedback (DFB) sections and an integrated phase tuning section [2], controlled by three dc currents. The Bragg wavelengths in the two DFB sections are detuned in order to generate two DFB modes. The mutual injection of lasing modes from one DFB section into the other, together with proper phase adjustment of the light waves via the integrated phase tuning section, leads to a coupled dual-mode lasing system with a very stable 60 GHz beating signal at 1540 nm. Further noise reduction (phase noise value of -100 dBc/Hz @ 100 kHz) is achieved by injecting subharmonic 10 GHz optical pulses into the SPL, which are generated by a gain-switched laser (GSL) in the CMCS.

The SPL output signal is externally modulated using an intensity modulator (MOD) for data transmission (Fig. 2). A 1.27 GHz subcarrier modulated by 155 Mbit/s offset quadrature phase-shift keying (OQPSK) is applied to the external modulator. Following transmission over a single mode fibre to the BS, the optical waves are split and applied to the OMCs. The RF signals feeding the 1 x 4 phased array antenna are obtained by optical heterodyning. The phases of the RF signals, and hence the antenna look direction, are steered by a fibre-based beamformer preceding the OMCs. The received signal is down-converted at the mobile terminal (MT) and fed to an OQPSK receiver. Error-free operation at 155 Mb/s (BER less than 10-10) was demonstrated, with no penalty for fibre distribution of the optical microwave signal or for remote stabilisation of the SPL.

Future broadband wireless connections can be made in a cost-effective way by using an SPL as the optical microwave source.

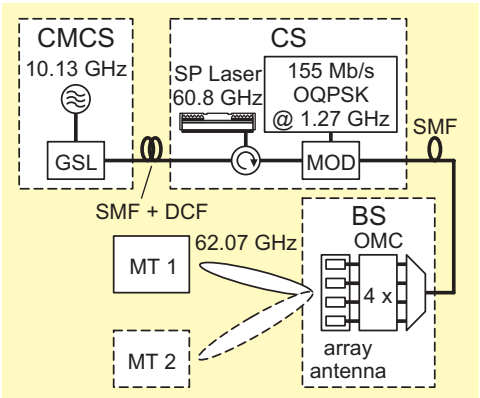


Fig. 1:
Broadband access system with hybrid-fibre-radio technology. CMCS: central master control station, CS: control station, BS: base station, MT: mobile terminal.

Fig. 2:
Setup for the transmission experiment

[1] G. Grosskopf et al., Intern. Microw. Symp., IMS 2001, Digest, vol. 3, pp. 1821-1824, May 2001.

[2] C. Bornholdt et al., Electron. Lett., vol. 36, no. 4, Febr. 2000, pp. 327-328.

Gerd Grosskopf (grosskopf@hhi.de)

Graph-Based Representation of Objects in Image Databases

Measures of similarity of images are important in computer vision. The goal of our research is to develop a representation of local image primitives that is invariant to translation, rotation and scale. Its usability in image retrieval is shown.

Retrieval of digital images based on image features rather than text descriptions has been the subject of considerable research effort in recent years.

Feature vectors, describing visual properties such as colour, texture and edge statistics, are calculated for either the whole image or parts of the image. Images are considered similar if the distance between their feature vectors is small.

Fig. 1: Graph-based description of image segments

The typical user searches for images in which semantic objects such as cars, houses or persons occur. These semantic objects cannot be described by feature vectors calculated on the whole image. An adequate description needs both a suitable representation of the visual properties of image parts and their relative positions.

In our research a new distance measure that can be used to compare either the whole or parts of segmented images was developed. It is based on the colour, shape and texture properties of image segments and their relative positions. The user can search for semantic objects based on interactively selected segments of images.

Fig. 2: Three sets of images. Each set contains images which were evaluated as being similar on the basis of the developed metric.

There is still no system that is able to automatically segment still images into semantically meaningful parts. Hence in our system, following a machine segmentation process, we offer the user the possibility of merging regions that belong together semantically. Extraction of MPEG-7 descriptors for each segment then takes place. We use the following descriptors: Scalable Colour Descriptor, Homogenous Texture Descriptor, Edge Histogram Descriptor and Bounding Box Descriptor.

In a second step the information-reduced images are represented by labelled graphs. This allows an image representation that is invariant to translation, rotation and scale. The set of all segment centroids is the set of nodes. Every node is labelled with an MPEG-7 feature vector. Edges, labelled with the distances between centroids, are introduced for each pair of nodes. The distances are normalized with respect to the image diagonal.

To find similar images, we calculate a distance measure for the labelled graphs. We have proved that this measure is a metric in the space of isomorphic classes of labelled graphs with the same lable sets. This can be important in using distance-based methods in computer vision, for instance in semantic recognition (person walks or sits), and in the area of machine learning (cluster methods).

[1] S. Bischoff, T. Sikora and F. Wysotzki, “A new distance measure for segmented images based on MPEG-7 descriptors”, submitted to European Conference on Computer Vision (ECCV ’02), May 2002, Copenhagen, Denmark.

Stefan Bischoff (bischoff@hhi.de)

Sensing People – a New Multimedia Project

Sensing People denotes functionalities that automatically yield high level information about people from lower level sensor data such as still images, videos or microphone signals. This information includes a variety of aspects concerning people, e.g. their number, their activity, their state, their gender, their identity and their mutual interaction. This contribution reports on a new project just started at the HHI.

Multimedia data may originate from ordinary cameras and microphones as well as from specialized devices integrated into notebook PCs, mobile phones, wrist watches, household appliances, etc. A large number of attractive applications become conceivable if computers, machines or the sensors themselves are provided with Sensing People functionalities.

In June 2001, a new project called "Sensing People – Intelligent Cameras and Sensors" started at the HHI. The project aims at the extraction of high level personal data from office and other scenes observed by three low level sensors: a microphone array, a CCD video camera and a CMOS optical device that gives a depth profile.

Fig. 1:
A general Sensing People scenario

To accomplish this, four partners are cooperating on this project. The Telecommunications Department at the Technical University of Berlin is working on microphone arrays to derive speaker positions and genders from acoustic data. The Fraunhofer Institute for Microelectronic Circuits and Systems in Duisburg is building a CMOS camera for depth profiling. The Fraunhofer Institute for Integrated Circuits and Applied Electronics in Erlangen concentrates on Sensor Fusion, and is responsible in this project for combining and analysing the data from all the sources. Finally, the Department of Interactive Media and Human Factors at the HHI Berlin is working on the analysis of the visual content of video images. It also coordinates the overall project.

The fusion of three sensor signals of different types (Fig. 2) makes the acquired information richer and more robust than would be possible with a single device. For example, combining video images with depth profiles gives more reliable estimates of peoples' positions, postures and activities. These data also support the extraction of speaker-specific features and the visual description of people by their appearance.

Fig. 2:
a) Speaker signal located by a microphone array
b) Video frame
c) Grey-value-coded depth profile from the CMOS camera

Further, simultaneous analysis of a set of different features helps to recognise who is in the office and what he or she is doing or intends to do. This information may help ubiquitous computers adapt to different users, and it may also help the users to communicate in a natural way with the computers.

Sensing People technologies can be exploited in smart houses, smart cars and smart machines. In addition, many other useful applications, including biometry, are conceivable with Sensing People technologies.

This work is supported by the Federal Ministry of Education and Research under grant 01 AK 900 B.

Thomas Ellerbrock (ellerbrock@hhi.de)

Hierarchical 3D Navigation in Image Databases

A new image retrieval and navigation system was developed. This system combines a three dimensional visualization of the image space with an intuitive hierarchical browsing environment. The image space is represented by "image maps" with different scales and user-adapted similarity metrics, analogous to road maps with different scales.

Retrieval of digital images based on image features rather than text descriptions has been the subject of considerable research effort over the last few years. Within this framework the MPEG-7 standard attempts to standardise suitable descriptors to allow many image search engines to access as many distributed images as possible, using unified and standardised descriptors. Various low level image descriptors are currently under consideration in the MPEG video group, such as colour and colour distribution descriptors and texture descriptors. While the MPEG-7 activity attempts to specify suitable descriptors, neither the search engines nor the methods for displaying the retrieval results will be specified by the MPEG-7 standard, which leaves a large degree of freedom for product developers to tailor their search and visualization technology to specific applications.

Most approaches to image database management have focussed on search-by-query. These methods require that users provide an example image. The database is then searched for images that are similar to the query. However, the effectiveness of search-by-query can be questioned, since it is often difficult to find or produce good query images, and, perhaps more importantly, repeated queries often tend to become trapped in a small group of undesirable images.

To overcome these problems, the user should to be provided with easy and intuitive access to the information in image databases, particularly when confronted with very large volumes of images. Hence similarity-based retrieval should return images that are displayed not only in order of increasing dissimilarity from the query, but also according to their mutual dissimilarities, so that similar images are grouped together rather than being placed along the entire returned list of images. Furthermore, it is important to provide the user with an intuitive browsing environment that iteratively guides the user through the image database – the human should be "in the loop". Only this combination of an intuitive visualization technique with a browsing environment based on an appropriately structured image database provides easy and intuitive access to information.

Therefore a new image retrieval and browsing system has been developed at the HHI [1]. Our approach uses the metaphor of road maps. Like road maps with different scales, ranging from a world map to a city map, the image space is represented by "image maps" with different scales and user-adapted similarity metrics. Beginning with a global view, containing only representative images (key images) of the entire image database, the user can enter any domain of the database by selecting appropriate key frames.

Three different technologies in combination guarantee an intuitive browsing environment. These are:

- 3D–visualization of the selected images, the "image map";
- Use of a new relevance feedback technique, which computes, based on the user's interaction, the appropriate image similarity metric for the retrieval and visualization process;
- Hierarchical organisation of the image database so it can be used with an iterative retrieval procedure which operates at scales ranging the global down to very fine.

The results obtained verify the attractiveness of this approach for navigation and retrieval applications.

This work was supported by the Federal Ministry of Economics and Technology of the Federal Republic of Germany under grant 01 MD 917/3

[1] T. Meiers, I. Keller and T. Sikora, "3D browsing environment for MPEG-7 image databases", submitted to S&T/SPIE Workshop on Storage and Retrieval for Media Databases 2002, 20-25 Jan. 2002, San José, California, USA.

Thomas Meiers (meiers@hhi.de)

Fast User-Adaptive Image Search Engines

The visualization of image databases is a task with widespread applications. We have developed a concise and intuitive user interface suitable for both E-Commerce and private image collections. It is possible to perform user-adaptive 3D visualization with very effective relevance feedback in real time. Currently, our modules use MPEG-7 features, but can be expanded to commercially relevant attributes.

To be successful, user interfaces for image databases must present objects in an appealing manner, must allow easy and intuitive navigation through the set of objects, and must highlight their characteristics.

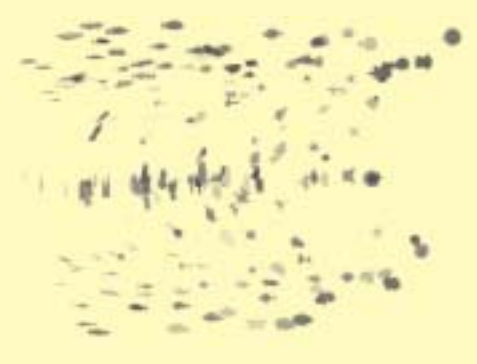
This can be done very successfully by utilizing the very high recognition capability of the human visual system. Visual similarity and visual order are major factors in searching. If images are arranged according to their similarity rather than the currently widespread list presentation, the search will not be so exhausting. In addition, the user can mark intuitively visual areas matching his or her interest and can refine the search in these areas. We prefer a 3D space for the visualization which is caused by a scene movement.

We use MPEG-7 features since this is likely to become the standard image content description language. However MPEG-7 is not restricted to visual features, and can easily be expanded with textural attributes, so that the features describing each image may cover a very high dimensional feature space, up to 300 or even more dimensions.

For visualization the feature space has to be reduced to 2 or 3 dimensions. We use Principal Component Analysis (PCA) for dimension reduction, which provides statistically optimum uncorrelated features. However, salient components in a pure statistical sense might not be relevant to the user, who may be interested in some particular aspects that are of minor statistical importance. Therefore a user-specific weighting of feature components is needed to take into account personal preferences.

This can be done in our system by an appropriate weighting of the covariance matrix used for PCA, followed by a new computation of the entire PCA, all done in real time. The user only has to change a slider corresponding to his or her special interests, giving an elegant and direct change of visualization. This enables the user to visualize those subspaces that appear relevant to him or her.

Though PCA is a linear technique, its performance is powerful and it is sufficient to compress high dimensional feature spaces to only three dimensions.



Result of a query on shape orientation

Additionally, we have implemented a true relevance feedback technique that presents only those images from the whole database that appear statistically relevant to the user. This technique adapts automatically and inconspicuously to the user's hidden search intentions, and gives the user a feeling of communicating with an "intelligent", flexible engine.

This work was supported by the Federal Ministry of Economics and Technology of the Federal Republic of Germany under grant 01 MD 917/3.

[1] I. Keller, T. Ellerbrock, T. Meiers and T. Sikora, "Fast user-adaptive weighting of MPEG7 descriptors for a visual E-Commerce interface", 3rd European Workshop on Image Analysis for Multimedia Interactive Services, Tampere, Finland, 16-17 May 2001.

[2] I. Keller, T. Meiers, T. Ellerbrock and T. Sikora, "Image browsing with PCA-assisted user interaction", IEEE Workshop on Content-based Access of Image and Video Libraries (CBAIVL-2001), 14 Dec. 2001, Lihue, USA.

Ivo Keller (keller@hhi.de)

Group Awareness for Mobile Applications

Information about the current availability of potential communication partners and their willingness to communicate is crucial for distributed groups (e.g. groups of teleworkers). In recent years HHI has developed ways of capturing and analysing data relevant to this problem for use in stationary computers. In future, mobile users will desire similar services.

Various studies have shown that information that supports group awareness is essential for successful communication between members of distributed work groups. This applies in particular to information about the current availability of potential communication partners and their willingness to communicate [1].

That kind of information can be provided by displaying indicators of user states or activities relevant to their availability for communication, such as being absent from the computer, talking, etc. (cf. the next contribution).

Indicators in the form of availability icons can be shown on the computer screen or on a mobile phone display. The figure shows icons for a WAP service developed at HHI.

Availability icons displayed on a WAP mobile phone

Another possibility for displaying availability information to mobile users is to use synthetic speech that tells a user if the desired partner is currently not at his or her desk, is involved in a talk with another person, is in a meeting, etc.

Data from which availability information can be derived, for either fixed or mobile computers, can come from cameras (by analysing motion as an indicator of presence/absence), microphones (by analysing the human voice as an indicator for being involved in an audio conversation), or keyboard and mouse activity (as an indicator for using the computer).

The KICK project has developed the software module BINDI (Busy Indicator), which can capture and process those data:

BINDI analyses the user's presence by analysing a video sequence captured by a webcam located on the user's monitor. The algorithm uses only small images from that ordinary webcam and has minimum processing requirements.

In order to find out whether speech communication is taking place, BINDI analyses the audio signal captured by a microphone near the user's desk and looks for frequency patterns typical of the human voice.

However, such means can usually not be used with real mobile devices, such as mobile phones or PDAs. In this case, novel means for sensing and analysing availability information need to be developed. HHI is currently considering R&D work on that issue. Among other things, sensors for movement, temperature and pressure are under discussion.

This work is supported by the Federal Ministry of Economics and Technology of the Federal Republic of Germany (BMWi) under grant 01 MT 901/7.

[1] B. Quante, R. Buss, L. Mühlbach, D. Przewozny and D. Runde, "An experimental comparison of two variants of an informal communication module for distributed workgroups", Proc. of the 18th Int. Symp. on Human Factors in Telecommunication, Bergen, Norway, 2001.

Lothar Mühlbach (muehlbach@hhi.de)

Supporting Group Awareness in Teleworking Applications – Human Factors Aspects

Telework, distributed workgroups and virtual enterprises will be common in the near future. Novel communication systems with user-friendly communication management are required for these working schemes. At present, simultaneous informal communication between distributed team members is rarely supported by conventional groupware systems. Since informal communication is unplanned, users need to be made aware of the current status of their co-workers.

A precondition for successful initiation of informal communication is to contact a person at a moment convenient to him or her. In face-to-face encounters one would usually refrain from speaking to a person who seems to be very busy or is involved in conversation with another person. But when at another location, it is difficult to decide whether or not a person is addressable due to the fact that communicative signals and awareness information are missing.

Video communications, however, which have the potential to transmit such cues, have turned out to cause user resistance due to fears of violating privacy.

In view of this we have developed a module BINDI (Busy Indicator) that automatically recognises whether the other user is present/absent at his or her workplace, is currently talking to someone else, or is using the computer. These cues serve as indicators of a person's availability for communication and are displayed in both a chat variant, with a conventional user interface similar to those of common chat systems, and in a virtual environment (VE), in which each user is represented by an avatar.

Fig. 1:
Scene taken from the virtual environment

The various user states are presented either as availability icons or in the form of avatar actions in the VE (see the figures).

Additionally, electronic calendar data are provided to predict a person's availability in the near future.

Results of an experimental field trial, in which three distributed project groups tested both variants during their everyday work, showed that the availability information provided by BINDI was useful and facilitated the assessment of a potential interlocutor's availability for informal communication, particularly when this information is provided by availability icons.

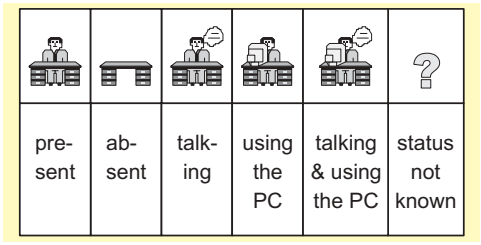


Fig. 2:
Availability icons

Availability icons turned out to be easy to interpret and to give an overview of ongoing group activities at a glance. The VE variant could produce a considerable degree of telepresence, and users who were used to virtual environments experienced the teleworker as being more present when using the VE variant, although subjects did not have the feeling of sharing a common room. The graphical representation of the entire work group in a virtual team room integrated the teleworkers visually, and this in turn increased the feeling of telepresence.

The acceptance of the tested variants was such that all users could imagine continuing to use the Chat variant after the end of the field trial.

Moreover, privacy concerns did not turn out to be severe with either variant.

This work is supported by the Federal Ministry of Economics and Technology of the Federal Republic of Germany (BMWi) under grant 01 MT 901/7.

Birgit Quante (quante@hhi.de)

Next Generation 3D Displays for Mixed-Reality Applications

Rapid progress in computer technologies will enable mixed-reality applications, in which computer-generated views of virtual objects and environments are combined in some proportion with the user's real environment [1]. The goal is to seamlessly integrate the virtual objects into the user's real workspace, thereby avoiding any unnatural perceptual artefacts and allowing direct interaction and precision manipulation. Ideally, there should be no noticeable difference between interacting with real and computer-generated objects. We have recently presented the first working prototype of a high-resolution mixed-reality 3D display to the public.

Most of the known 3D display concepts have one serious disadvantage when it comes to supporting direct virtual object manipulation with the hands or other physical tools. This problem is arises because the stereo images are displayed on a physical display screen, whereas the spatial position of the virtual object may stereoscopically appear to be at a closer distance (e.g. within reach). Users have to accommodate, or focus, their eyes at the depth of the screen surface, in order to see an unblurred, clear stereo image, whereas the lines of sight converge at the apparent position of the virtual object. The resulting conflict between accommodation and vergence is a potential contributor to eye strain and, moreover, it is a major factor in perceptual errors with stereoscopic displays (regarding the perceived depth and size of the virtual object).

As well as the accommodation-vergence conflict with current 3D displays, there will almost always be an accommodation mismatch between real and virtual objects. The accommodation distance for virtual objects is always the distance from the viewer to the display screen, whereas the accommodation distance for the real object corresponds to the position of the object. When, for example, the user tries to align the finger or a tool with the virtual object, he or she will see either the virtual object (accommodating on the screen) or the real object (when looking at it) in full focus, but not both in focus at once. Natural interaction, in which both the virtual and real objects are seen in full focus, is hence not possible.

We have found a solution to this problem in the Accommodation 3D Display [2], where the stereo image pair is focussed on an aerial image plane floating in the user's grasp area (Fig. 1). The prototype display provides a symmetrical stereo resolution of 2 x (1024 x 768) pixels. The 3D display creates two circular viewing windows of diameter 65 mm at a distance of 70 cm from the display. Looking through the windows, the left-eye and right-eye images are fused, forming a 3D image which floats 20 cm in front of the display. Hence the accommodation and convergence distances are both fixed at about 50 cm from the user's eyes, allowing comfortable and unhindered hand interaction with a virtual object (Fig. 2). The two high-resolution images forming the stereo pair are optically channelled to the eyes without any visible crosstalk (perfect stereo separation).

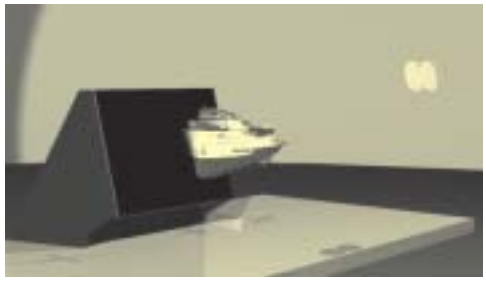


Fig. 1:
Basic design of a 3D display for desktop mixed-reality applications. The aerial 3D image of the virtual object floats in the user's grasp area. The two circular regions on the right indicate the stereo viewing windows.

Fig. 2:
This original photo demonstrates that both the user's hand and the virtual object appear at the same focal distance. The 3D image is very bright (more than 500 cd/m^2) because of the optical principle used in the display.

This work was supported by the Federal Ministry of Education and Research under grant 01 BK 802.

[1] The term Mixed Reality was coined by Paul Milgram, University of Toronto.

[2] S. Pastoor and J. Liu, "3D display and interaction technologies for desktop computing", in Three-Dimensional Television, Video and Display Technology, edited by B. Javidi and F. Okano, Springer Verlag (in print).

Siegmund Pastoor (pastoor@hhi.de)

Tracking Technologies for Multimodal Human-Computer Interfaces

Sensing people and their behaviour is the most important part of perceptual user interfaces. For this purpose, we have developed in the mUltimo3D project a number of real-time image segmentation and pattern recognition algorithms for detecting and tracking people's head/eye position, hand position and gestures, and gaze direction. Great efforts have been made to achieve robust tracking performance under various lighting conditions and varying sizes and orientations of the tracked objects.

Computer vision systems for recognizing and tracking people and their behaviour should be fast, accurate, robust and informative. The common challenging problems are to deal with changing environment (illumination, other objects of no interest moving in the background) and changing appearance of the tracked objects (size, non-rigid form, orientation). Also, to make vision systems useful for human-computer interaction, the whole system delay must be kept to an acceptable range.

In the mUltimo3D project we use a set of cameras to track people's head/eye position, gaze direction, hand position and simple gestures.

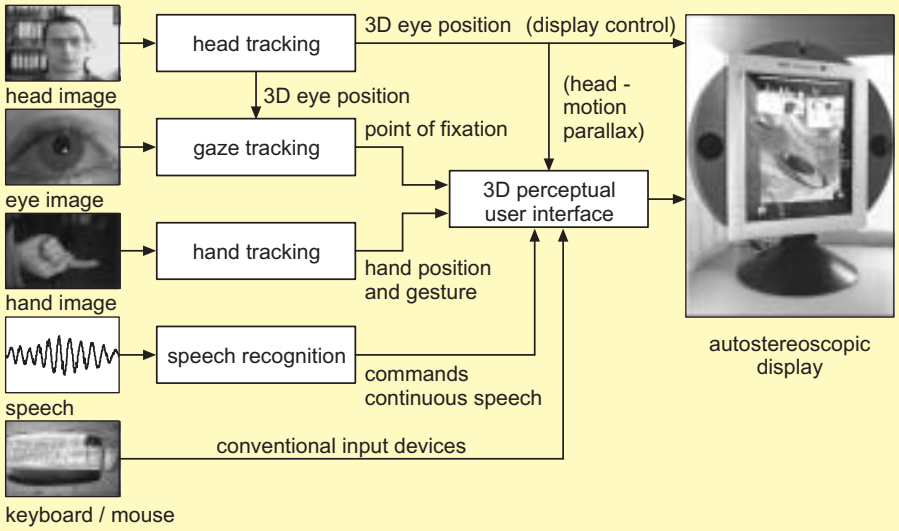
Head/eye tracker: In the initialisation phase, user-specific eye patterns are found in video images by detecting the user's eye blinking or by means of a pre-stored eye database. After that, the eye patterns are tracked using the block matching technique. In order to cope with variation of the illumination, two strategies are used: 1) both the pre-stored reference eye patterns and the candidate patterns in the current image are luminance-adapted before being compared with each other; 2) the gain of the video grabber is actively controlled by the brightness of the actual image (or the region of interest), to ensure that the captured images are not too dark or too bright due to the varying lighting conditions.

Gaze tracker: In order to estimate the point of fixation of the user, the user's eye is illuminated by several low-intensity infrared lights. The middle points of both the pupil and the highlights are detected by the cornea-reflex method. A head-fixed transformation is applied to compensate for the influences of free head movement and pose changes of the gaze camera. A self-calibrating algorithm is used, which significantly simplifies the troublesome calibration process.

Hand Tracker: Our hand tracker uses two infrared-sensitive cameras and an infrared light source arranged next to the cameras. Simple hand gestures (hand opened or closed and the pointing direction of the index finger) are recognized by analysing the distribution of the hand vectors, which point from the centre of the hand to the fingers. The determination of the 3D hand position is based on a correspondence analysis.

This work was supported by the Federal Ministry of Education and Research under grant 01 BK 802.

Jin Liu (liu@hhi.de)



Four cameras are arranged around the display and next to the keyboard – one for measuring the head/eye position, one for tracking the gaze direction, and two for tracking the hand position and gesture

Human Factors in Multimodal Human-Computer Interaction

Multimodal interaction is expected to enable end users with varied backgrounds to master with ease the increasing functionalities of computers, and to make the use of computers in general an enjoyable experience. Humans have developed various modalities to communicate with others and to interact with their physical environment. The basic idea of a multimodal interface is to adapt such familiar modalities to the particular requirements of human-computer interaction.

Humans perceive information through multiple input channels using the senses of sight, hearing, touch, smell, taste and balance. Perception via the visual and auditive modalities generally outperforms the haptic, olfactory and gustatory modalities in terms of bandwidth and spatial and temporal resolution of the information transmitted, which is one of the reasons why visual and auditory displays have dominated human-computer interaction. Various output channels, such as speech, gestures and written text, are used by humans to communicate with others.

The interest in multimodal interfaces is based on the assumptions that: (1) a much higher bandwidth is possible with these systems; (2) different modalities excel at different tasks; (3) errors and disfluencies can be reduced dramatically, since the different channels can complement and disambiguate each other; (4) multimodal interfaces are more natural and hence more engaging.

Multimodal output leverages the human senses and the perceptual system because we can perceive several things at once; multiple input leverages the human motor capabilities and communication skills because we can do several things at once [1]. The concept of multimodal interaction means not simply the provision of the display and sensory techniques that enable such interaction with a computer (which is of course not simple from an engineering viewpoint). The real challenge is to fuse the various modalities in an intelligent way, taking into account how the integrating modalities relate in a natural environment. To find guidelines for this is a major task of our current research (see the figure and reference [2]).

Existing results indicate that speech input seems to be relevant in any multimodal system, probably because speech is the most powerful human output modality. Users generally prefer combined inputs over systems offering only a single modality. Combining several modalities, such as hand gesture, eye gaze and speech input, increases the overall system performance.

The various input modalities have quite different characteristics. For example, positioning a cursor by eye gaze interaction is quicker but less precise than positioning by hand movement; natural-language speech input is perfectly suited to descriptive tasks, whereas hand gestures are the ideal solution for the direct manipulation of objects. Challenges in designing an efficient user interface lie in minimizing the time needed to switch among the modalities available and in simplifying the learning process needed to understand how interactions with the computer relate metaphorically to corresponding processes in the real world.

Multimodal human computer interface using a 3D display with speech input and output as well as conventional input devices (keyboard, mouse). Additionally, various video trackers sensing the user's head position, eye movements (gaze point) and hand gestures are available for interaction. This system is currently being used in user trials, in order to optimise system parameters and to develop guidelines on how to fuse various modalities in an intelligent way.

This work was supported by the Federal Ministry of Education and Research under grant 01 BK 802.

[1] G. Robertson: "Leveraging human capabilities in perceptual interfaces", talk at the PUI Conference, 1998.

[2] S. Pastoor and J. Liu, "3D display and interaction technologies for desktop computing" in Three-Dimensional Television, Video and Display Technology, edited by B. Javidi and F. Okano, Springer Verlag (in print).

Siegmund Pastoor (pastoor@hhi.de)

CABAC – Advanced Entropy Coding in the Draft ITU-T H.26L Video Compression Standard

A new entropy coding scheme for video compression is presented. Context models are utilized for the efficient coding of symbols. A novel binary adaptive arithmetic coding technique is employed to match the conditional entropy of the coding symbols, given the context model estimates. An adaptation mechanism is used to keep track of non-stationary symbol statistics. Our new approach has been adopted by ITU-T as an advanced entropy coding method in the current ITU-T H.26L test model (TML).

In 1998, the Video Coding Experts Group of ITU-T Study Group 16, Q.6 (earlier known as Q.15) started to develop a new video compression algorithm in a standardization project named H.26L. The promotion of the first version (H.26L baseline) is scheduled for late 2002. The main two targets of this project are: a) coding efficiency (it aims to reduce the bit-rate for a given subjective quality by about 50 %, compared to H.263+ or MPEG-4 Advanced Simple Profile); and b) network friendliness. Considerable improvements in coding efficiency of 30-50 % have already been achieved with the current version of the test model (TML8). The main features of TML8 are as follows:

- Spatial intra-block prediction
- 4 x 4 block transform
- Motion compensation with multiple block sizes
- Multiple-reference frame prediction
- Quarter-pel motion accuracy
- Rate-distortion optimised encoder decisions

The basic entropy coding method in TML8 uses a single, universal variable length code (UVLC) for all coding elements. It has been shown that the UVLC is not optimal with respect to coding efficiency. The simple design of the UVLC assumes that the underlying probability distribution is static and ignores correlations between symbols. In addition, the need to use at least one bit per symbol calls for a joint coding of symbols.

In order to improve on these restrictions of the UVLC design, we have developed a fundamentally different approach based on context-based adaptive binary arithmetic coding (CABAC). The concepts behind CABAC are known to lead to highly efficient entropy coding. Similar techniques are used in the emerging still image compression standard JPEG-2000, but so far they have rarely been used for video compression.

The advantages of our approach are threefold compared to entropy coding using a fixed variable length code:

1. Context modelling provides estimates of conditional probabilities of the coded symbols. Utilizing suitable context models, inter-symbol redundancy can be exploited by switching between different probability models, depending on previously coded symbols.
2. Arithmetic codes permit a non-integer number of bits to be assigned to each symbol of the alphabet. Thus the symbols can be coded almost at their entropy rate. This is extremely beneficial for symbol probabilities much greater than 0.5. In this case a variable length code has to use at least one bit, whereas arithmetic codes may use a fraction of one bit.
3. Adaptive arithmetic codes permit the entropy coder to adapt to non-stationary symbol statistics. For example, the statistics of motion vector magnitudes vary over space and time as well as for different sequences and bit-rates. Hence, an adaptive model taking into account the cumulative probabilities of previously coded motion vectors leads to a better fit of the arithmetic codes to the current symbol statistics.

**Sample reconstructions at 16 kbit/sec.
Left: H.26L using CABAC.
Right: H.26L using UVLC**

By using our new CABAC scheme instead of UVLC in the TML, large bit-rate savings of up to 30 % can be achieved. As a remarkable outcome we have observed high coding gains not only at high bit rates, but also at very low rates.

Detlev Marpe (marpe@hhi.de)

MPEG Coding Efficiency Tests

The Moving Picture Experts Group (MPEG) recently issued a Call for Proposals on new tools to further improve video coding efficiency above that of their MPEG-4 Visual standard. The current project of the ITU-T Video Coding Expert Group, known as H.26L, took part in MPEG's coding efficiency tests in July 2001. The HHI has provided a rate-distortion-optimized encoding strategy for both MPEG-4 Visual and H.26L, and this was chosen by the standardization bodies as their standard encoding method for the coding efficiency tests.

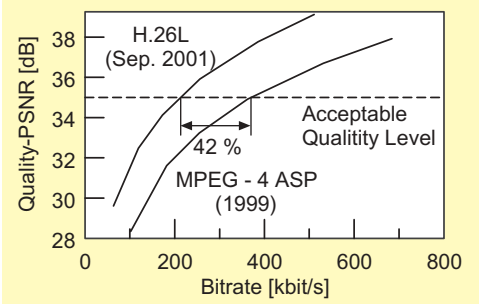
MPEG issued a Call for Proposals on New Tools For Video Compression Technology [1] at the beginning of 2001. For the subjective tests, carried out in July 2001, various video sequences were used to test the coding efficiency, in comparison with MPEG-4 Visual, at different bit rates.

The ITU-T Video Coding Expert Group (VCEG) is currently developing a new video coding standard known as H.26L [2]. The H.26L project, to which the HHI is actively contributing, took part in the MPEG coding efficiency tests.

Common to the ISO/IEC standard MPEG-4 Visual and the ITU-T project H.26L is that they both define so-called block-based hybrid video coders. The basic source coding algorithm is a hybrid of inter-picture prediction, to take advantage of temporal redundancy, and transform coding of the prediction error signal, to reduce spatial redundancy. Although the H.26L design basically follows that of earlier video coding standards such as MPEG-4 Visual, it contains new features that enable it to achieve significant improvements in compression efficiency compared to previous coding standards.

MPEG-4 Visual and H.26L specify only the bit-stream syntax and the decoding process. The encoding process is left out of the scope to permit flexible implementations and achieve interoperability. A rate-distortion-optimized coder using Lagrangian techniques was developed at the HHI for both MPEG-4 Visual and H.26L. In both cases the improved encoding strategy provides visible performance gains compared to the previous encoding strategies. Following a proposal by the HHI, the Lagrangian encoding strategy was integrated into the current test model TML-8 for the H.26L project. Both rate-distortion-optimized coders have been chosen by the standardization bodies, MPEG and ITU-T, as their standard encoders for the coding efficiency tests in July 2001. For MPEG-4 Visual, an alternative implementation by UBVideo, which mainly follows the approach of the HHI, was also provided, and the MPEG-4 anchors were chosen from both implementations.

For the set of sequences and bit rates specified in MPEG's Call for Proposals on New Tools For Video Compression Efficiency, the H.26L-compliant encoder achieved performance gains of 1.1-3.6 dB over the MPEG-4 encoder. Subjective tests carried out at the HHI showed that, for all cases in MPEG's test set, sequences coded at 512 kbit/s with H.26L are subjectively equivalent to the same sequences coded at 1024 kbit/s with MPEG-4 Visual. This corresponds to a bit rate saving for H.26L of about 50 % over MPEG-4 Visual. At lower bit-rates the tests seem to indicate bit rate savings of 30-40 %. The figure shows a PSNR vs bit-rate comparison of the two codecs for the sequence Foreman.



Performance comparison of the current H.26L test model and the MPEG-4 Advanced Simple Profile for a typical video test sequence

[1] ISO/IEC JTC1/SC29/WG11, Call for Proposals on New Tools For Video Compression, Doc. N4065, 2001.

[2] G. Bjontegaard and T. Wiegand, H.26L Test Model Long Term Number 8 (TML-8) draft 0, ITU-T VCEG, June 2001.

Heiko Schwarz (hschwarz@hhi.de)

Multimedia Systems based on MPEG-4 for Internet and Mobile Transmission

The transmission of multimedia data over currently available IP-based networks is described. The coding scheme used for transmission is compliant with both MPEG-4 and the proposed transmission scheme. The xperimental system described here is for the evaluation of IP-based multimedia data transmission over mobile networks.

Streaming media distribution is a rapidly growing application, especially with the upcoming broadband mobile phone networks and the increasing number of internet subscribers with broadband access, which enables high quality multimedia applications. There are already several solutions available from vendors such as Apple, Microsoft and Realnetworks. Unfortunately these solutions use different transport schemes and media types, incompatible with each other and mostly not usable for mobile transmission. The recently released ISMA specification offers an open standard for media streaming, with the goal of reducing market fragmentation. Especially for user convenience, it focuses on a common media format. The experimental framework described here will be extended to full compatibility with the ISMA streaming standard.

The streaming framework is built around the MPEG-4 standard and provides support for real-time encoding and decoding of MPEG-4 media to satisfy the demands of live transmission. Several aspects relating to wide area network distribution are considered, such as cascading and forwarding.

The signalling scheme is based on RTSP, which uses TCP/IP as the transport protocol. To fulfil the requirements of media streaming, a request-response scheme for server-client communication is implemented. Communication on the signalling channel is established using a small set of commands. A typical streaming session can be divided into three phases: negotiation, streaming and shutdown.

The negotiation phase incorporates two obligatory steps. First of all, a *DESCRIBE* command is sent to the server for the requested media. The response contains the media and initial object descriptions for decoder initialisation in SDP format. The client then chooses from the available streams and issues at least one *SETUP* command, which contains the desired method of stream transport. In the case of RTP transport, the client's UDP port pair and unicast/multicast choice are passed as arguments to the setup command.

After establishing the streaming connection, the second phase starts with the sending of the PLAY command, which starts the transmission over the RTP channels and allows positioning within the stream to achieve a "skip" or "jump" feature.

The user is able to interrupt the streaming transmission by using the *PAUSE* command. The third phase, the shutdown, of a typical media transmission is initiated by the *TEARDOWN* message, which ends the streaming session. The media transmission is achieved with RTP, which is based on the UDP datagram protocol. For each media channel one RTP channel is used. To avoid unnecessary data packet overhead, the data are packed without using the MPEG-4 SL packetization scheme. Synchronization is performed using RTP timestamps, which are already defined in the RTP specification.

The currently implemented framework comprises a server for data retrieval and real-time media encoding. The players are available for different platforms, such as Win2k and Linux. To be able to test the application in real mobile environments, the player is also available for WinCe-based PDAs. The IP-based networks that were tested included LAN, Wireless LAN, T-DSL and GRPS under various conditions. For more information, refer to [1].

[1] B. Stabernack and H. Richter, "A multimedia streaming framework for mobile applications – A first approach", Proc. 12th PacketVideo Workshop 2002, Pittsburgh PA, April 2002.

Benno Stabernack (stabernack@hhi.de)

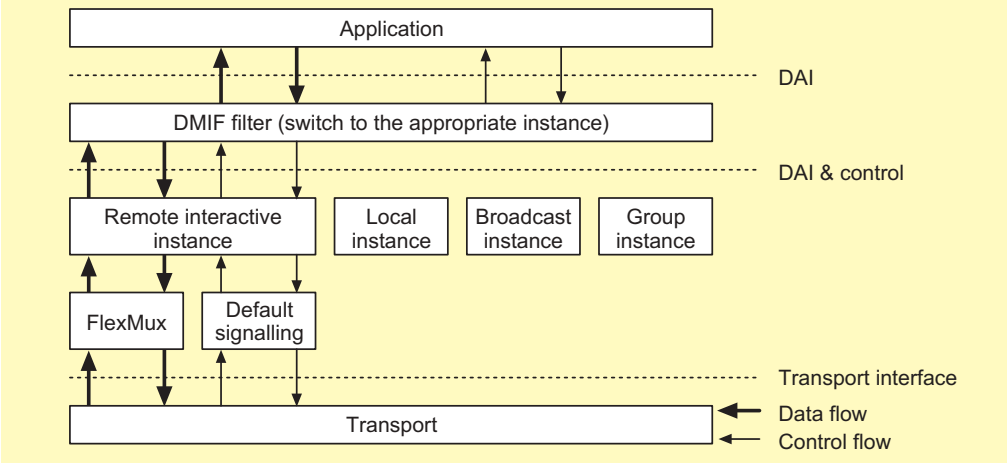
MPEG-4 Streaming Solutions using the Delivery Multimedia Integration Framework

Next generation multimedia applications are based on the evolving MPEG-4 standard. The MPEG-4 Delivery Multimedia Integration Framework (DMIF) provides a standardised and flexible technology to support both various transmission scenarios and local storage. This contribution describes a reusable and well-designed software implementation of MPEG-4 streaming using DMIF.

Several HHI projects with industrial and research partners use MPEG-4 technologies. These projects differ in their application area, transmission technology and target platform. In order to support all the different requirements defined by these projects, a project has been launched that implements a generic concept with a flexible design and reusable MPEG-4 software components. This contribution focuses on MPEG-4 DMIF, which is the key to supporting various transmission technologies through a common software library.

It is a key feature of the DMIF standard that it hides the transmission layer from the application by inserting the DMIF application interface (DAI). Any application, whether in the automotive, TV, mobile or PC industry, can access streamed content through this API.

In a similar manner, a well-designed DMIF implementation should separate issues that are specific to the transmission media from those DMIF functionalities that are common to all scenarios.



Generic design of the Delivery Multimedia Integration Framework

The diagram illustrates the architecture of HHI's DMIF implementation. The DAI allows the application to set up the correct instance for the chosen transport media. The implementation provides the specific features of each media access protocol in separate instances, and uses a common transport interface, which allows the mapping of the DMIF default signalling to the transport-specific signalling.

The software development of the DMIF library was carried out using state-of-the-art software design methodology and a variety of tools. The architecture was designed using the standardised Unified Modelling Language (UML) with Rational Rose. The C++ source code, its related design data and the documentation are all managed under source control with the Concurrent Versions System (CVS). Any project requiring MPEG-4 streaming has access to the library via the CVS server. An automated process, using Rational SoDA, generates a consistent and up-to-date version of the documentation. It is made available, as both a hyperlinked Word document and an HTML web page, to all projects over the Intranet of the image processing department. In order to support multiple target platforms, the implementation makes use of the HHI Multiple Operating Systems Library (MSysLib), which provides a common interface for objects that are specific to the operating system, such as threads, sockets and file I/O to name but a few.

The DMIF library is thus a powerful and easy-to-use tool for MPEG-4 streaming solutions.

Jens Güther (guether@hhi.de)

Audio Player on DSP and RISC Processors

The availability of powerful DSP and RISC processors makes possible the implementation of complex audio codecs on dedicated modules in hand-held devices. MPEG-4 audio encoding and decoding for real-time applications has been implemented using both a Texas Instruments DSP and the RISC processor "StrongARM". This paper discusses the implementation results.

The data rates of uncompressed high quality audio signals (e.g. PCM 16 bit at 44.1 kHz) are very large. There has therefore been a proliferation of audio compression techniques and formats over the last few years. MPEG-2 layers 2 and 3 are frequently used algorithms for different types of internet audio (layer 3 is well known as MP3). Other standards for multimedia applications are AAC and CELP.

AAC (Advanced Audio Coding) is more efficient than previous compression techniques because of its many improvements. This standard supports sampling rates from 8 kHz to 96 kHz and provides audio of almost CD quality at a very low bit rate (64 kb per channel). The AAC standard is also capable of handling up to 48 channels in one bit stream, so it is suitable for any multi-channel application. MPEG-4 AAC can be used in a wide range of applications such as home cinema, internet audio and hand-held players and recorders.

The high coding efficiency of AAC is achieved by a combination of several techniques, including high resolution filter banks, adaptive prediction and Huffman coding. Due to these computationally intensive algorithms, the encoding process requires a huge amount of computational power. Various hardware solutions for implementing audio codecs have been evaluated.

Real-time implementation on a DSP

A floating point architecture is mandatory for the implementation of the encoder because of the required precision, whereas the AAC decoder can be implemented on a 32 bit integer processor. The TMS320 C6x DSP series from Texas Instruments [1] has been chosen for the implementation of the AAC codec to realize a hand-held stereo player/recorder.

The core of this application is a DSP operating with a 167 MHz clock and a 3.3 V power supply. The DSP is booted from flash and works with 1 MB of SBSRAM. A Multi Media Card (MMC) and a standard RS232 interface are available for data input and output. Encoded audio data are stored on the MMC. The configuration of this hand-held device can be done by remote control, while the status of the application is shown on the integrated device display.

Two inputs for analogue audio data are available: stereo LINE IN and MIC IN. One stereo LINE OUT port is used for audio output. A high fidelity 16 Bit Audio ADC/DAC converts analogue data into digital data and vice versa.

Player implementation on a RISC processor

RISC processors such as the SA-1110 (StrongARM) from Intel [2] are possible alternatives to DSPs. The processor performance and the low power consumption enable the implementation of modules for hand-held systems, especially for audio applications.

The SA-1110 module used for the codec implementation incorporates a 32 bit StrongARM with a CPU clock at 206 MHz. This platform supports up to 32 MB of fast flash memory and uses Embedded Linux as the operating system.

The player supports a graphical user interface and includes decoders for AAC, MP3, CELP and MPEG-4 Video. The algorithms were ported and optimised for the StrongARM processor architecture, resulting in high performance implementations. For all three audio standards the decoding process can easily be achieved, but real-time encoding with fixed-point arithmetic requires much optimisation, as the ongoing work shows.

[1] Texas Instruments DSP Technology:
http://dspvillage.ti.com/docs/dspproducthome.jhtml

[2] Intel StrongARM:
http://www.unique.memec.com/uk/uniquesolutions/pdasolution/sa1110/sa1110.htm

Maati Talmi (talmi@hhi.de)

VPS – a DSP-Based PCI Board for Real-Time 3D Video Processing

Based on low-cost multimedia processors, the VPS architecture combines state-of-the-art PC technology with standard video interfaces for studio applications. Originally designed for an Immersive Videoconference System, the modular, scalable and cost efficient multiprocessor structure can also be used in other demanding signal processing applications.

Drastically increased processor performance, large varieties of PCI components and comprehensive software development tools for standard PCI architectures also give new possibilities for complex video-processing architectures.

Video processing extensions for the VIRTUE (VIRtual Team User Environment) conference terminal are based on a newly developed VIRTUE Processor Station (VPS), and realize the advantages of a PCI-based system architecture. The VPS architecture aims to meet the requirements for multiple camera interfacing, support of flexible system topologies using a modular structure, and cost-oriented scalability.

The basic element of the VPS is a subsystem containing four Trimedia processor cells embedded in the host's PCI hierarchy using a transparent PCI bridge. Multiple subsystems can be used to enhance the overall processing power. To bypass bandwidth limitations on the PCI buses, the system architecture offers three ways of communicating between the processor cells and other system components (Fig. 1). Method A refers to data transfers using the transparent PCI bridge. This method is recommended only for communication with non-VPS devices such as the graphic adapter or system memory, and should be rarely used for communication between VPS cells. VPS cells with high data exchange rates should be placed in the same package, so that the host PCI bus is not accessed (Method B). If the data rate exceeds the bandwidth limitation on the local PCI bus, unidirectional connections (Method C) may be used to unload the bus. Unidirectional connections are based on the compatible digital video interfaces of each processor cell. The combination of these three methods gives the flexibility to balance bandwidth requirements for various video processing tasks.

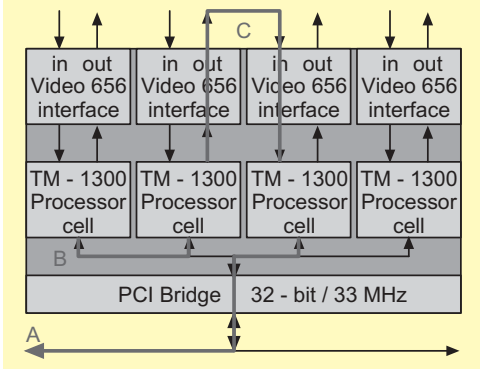


Fig. 1: VPS subsystem

The VPS concept features an open architecture based on a PCI processor card containing the Trimedia processor systems (Fig. 2) and a separate daughter card containing the video interfaces. The common video interfaces are the TriMedia video ports (low-voltage TTL 656 interfaces), which give low-cost designs for daughter boards containing interface circuits for serial 656 ECL (SDI, SMPTE 259M) interfaces, Channel Link LVDS interfaces or other digital video interfaces.

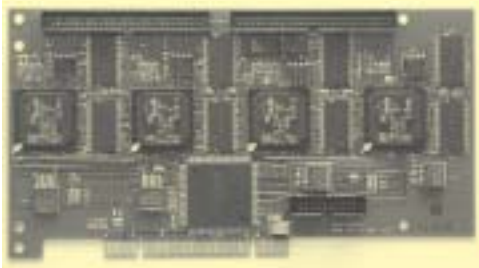


Fig. 2: VPS Trimedia board

The mechanical specification results in a package which does not exceed the maximum component height of a PCI expansion card. A low-cost Channel Link interface card that provides four video input ports, four video output ports and a router FPGA has been developed, and meets the requirements of the VIRTUE system. A more flexible solution is a SDI/LVDS interface card that comes with dynamically configurable router FPGAs (design downloaded from Trimedia).

VIRTUE is a project within the European Union's Information Societies Technology Programme (IST).

Michael Karl (karl@hhi.de)

E-Cinema – an Approach to Digital Cinema

In contrast to video, audio and internet media, which are nowadays processed completely digitally, the cinema industry seems to have missed the connection to up-to-date technology. One reason for this stagnating development is the unavailability of several key components because to their very high technological requirements. The E-Cinema project has been started with the objective of finding an approach to digital technologies which can realize its advantages for cinema, in order to close the gap between traditional cinema and the new digital multimedia revolution. A completely new service possible with digital cinema will be the ability to also show live events such as the Olympic games or great performances.

Each year about 3.5 billion cinema tickets are sold worldwide. Technology has not changed over the past decades: film material is exposed, processed, edited, multiplied in film labs, and shown using a 35 mm film projector. Digital processing in the film industry is rarely used, except when special effects are added. Copying the film material is an elaborate and expensive process, which induces a loss of quality, as does repeated projection. Today studios are responsible for supplying prints to theatres. The studios manufacture them and pay their cost.

The absence of digital processing comes about because of the very high technical requirements of a complete digital processing line. Even when films are produced digitally, the end of the chain is an analogue 35 mm film, because the main problem is the theatre projector with an adequately high resolution. Therefore most of the key components are also analogue, which impacts on the connections to other media and applications.

The objective of the E-Cinema project is the realisation and standardisation of a complete digital cinema system chain, starting with the capturing process, following with postproduction and then distribution by digital transmission (download and online modes), and finishing with the reproduction and local media storage.

Key points being investigated in the E-Cinema project are:

- Digital cameras with online compression and mobile data storage
- Real-time encoding and decoding for distribution via cable or satellite
- High resolution digital projection
- High quality spatial audio recording and playback
- Electronic data storage systems, archives, encryption and IP management

The HHI is working mainly on the distribution and receiving part of the cinema system chain. To solve the problem of high resolution reproduction, a modular configuration of the projection system is proposed. The system consists of multiple projectors, each working at High Definition resolution. To get a real immersive impression, as required for cinema applications, the different views will be merged together seamlessly by the UHDTV (Ultra High Definition Television) merger unit. The hardware architecture developed for the receiving part of the E-Cinema prototype system is shown in Fig. 1. It comprises three Hyperboxes (MPEG-2 HD Recorder/Decoder/Synchronizer) and the HiMerger for combining the different views to an ultra-high resolution picture.

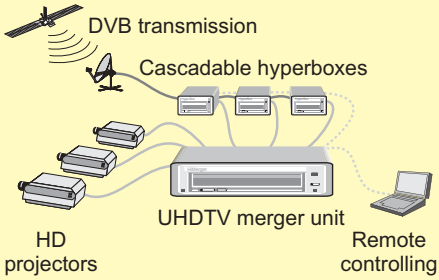


Fig. 1: Receiving part of the digital cinema system chain developed by HHI

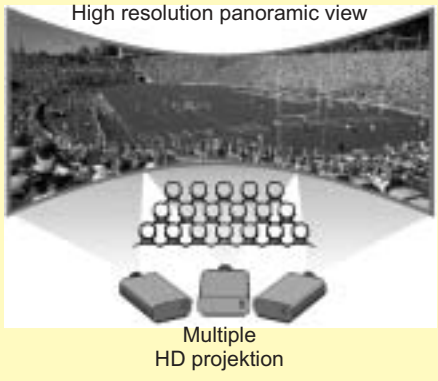


Fig. 2: Seamless ultra-high resolution view by multiple HD projectors

This work is supported by the Federal Ministry of Education and Research under grant FKZ 01 AK 040D.

Ulrich Höfker (hoefker@hhi.de)

Real-Time Solution for Depth Estimation in Immersive Media Applications

The aim of immersive media applications being developed at HHI is to render arbitrary virtual views of a scene. A key ingredient of immersive systems is disparity estimation, which provides depth information in real time. An algorithmic framework has to be developed which is a trade-off between quality of the result and the real-time constraint.

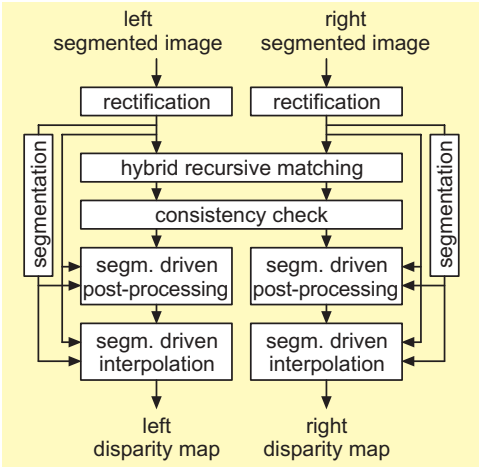
Real-time depth estimation in natural stereo image pairs plays an important role in a large number of applications. Depth estimation is performed by the matching of points in two images such that the matched points are the projections of the same point in the 3D scene. The disparity map obtained from this matching process can be used to render a virtual view of the scene by an image-based rendering technique using knowledge of the stereo geometry. This is performed in immersive media applications such as immersive TV or immersive video conferencing. Highly reliable dense disparity maps have to be processed in real-time for these applications.

Real-time disparity estimation framework

To reach this goal an algorithmic framework has to be developed which is a trade-off between quality of the result and the real-time constraint. The idea of this framework is to estimate disparities on a sparse grid (4 x 4 or 8 x 8), to post-process them, and then to interpolate them to form dense disparity maps.

Disparities are estimated with a hybrid recursive matching (HRM) approach, which unites the advantages of block-recursive matching and pixel-recursive optical flow estimation in one common scheme. Its computational requirements are met by the efficient selection of a small number of candidate vectors, guaranteeing both spatial and temporal consistency of the disparities. This algorithm has already been used successfully for fast motion estimation in MPEG coding and standards conversion.

However, disparity analysis requires more than just a straightforward application of HRM. The crucial problem is to produce correct disparities in every area of the image. In particular, occlusions and homogeneous or less structured regions cause visible errors in the disparity maps and lead to artefacts in a synthesized virtual view. To cope with these problematic areas, the sparse disparity maps of the HRM have to be post-processed to create a map of highly reliable disparities. In a first step the mismatches are detected and then substituted using an intelligent interpolation and extrapolation scheme. A consistency check is used to detect mismatches. The detected mismatches are rejected and replaced using an interpolation/extrapolation scheme that guarantees that depth discontinuities at object borders are retained. Segmentation and colour information from the original images is used to perform this task.



Another problem is that a simple interpolation scheme in the dense field calculation would lead to incorrect disparities at depth discontinuities. To prevent these errors a similar intelligent interpolation/extrapolation scheme is used when enlarging the disparity maps to full resolution.

The disparity estimation and the post-processing procedure run on a fast Pentium III system at full CCIR 601 resolution.

This work is supported by the Deutsche Forschungsgemeinschaft (DFG) under grant DD 20 9 11.

Nicole Brandenburg (brandbg@hhi.de)

View Combining and Novel View Synthesis for Image-Based Rendering in 3D Video-Conferencing

In order to obtain an image-based immersive presence in a virtual world, some form of multi-view representation is required. With 3D videoconferencing applications in mind, two non-conflicting view-combining approaches are introduced. The choice between them is dependent on whether compression or scalability is important to the overall system.

The goal of immersive video-conferencing systems is to allow geographically separated conference participants to have the full spectrum of experiences they are used to in real-world meetings.

To achieve this goal, 3D images of the participants are synthesised and positioned around a shared virtual table. In order to generate the required realistic 3D video objects, a multi-view camera setup captures the conferees, while disparities that represent the depths of the video objects are estimated from corresponding images. This virtual 3D scene is then rendered onto a 2D display using a virtual camera whose placement coincides with the current position of the conferee's head.

Regardless of the system configuration of the teleconferencing application, a multi-view representation of the 3D video objects is required. The term 'view combining' refers to the way in which the original images from the cameras are initially combined to obtain the required surface texture and disparity information to synthesize virtual views of the conferee. Here I present two non-conflicting approaches to view combining; the choice of which technique to implement is dependent on whether compression or scalability is more important to the overall system.

The first approach is Incomplete 3D, which is a compact disparity-based multi-view data representation that was developed in the context of the MPEG-4 multimedia standard [1]. Disparity analysis between reference images is used to limit the number of pixels that must be encoded. Each area that is visible in more than one reference image is encoded only once, and with the highest possible resolution.

This approach eliminates redundant image content in multi-view images. This is done directly after using these redundancies in the search for point correspondences, but before encoding, thus giving higher compression.

The Intermediate View approach warps the two original images to an intermediate derived position that is system defined. This warp is generated using trilinear warping techniques. The intermediate view can be thought of as coming from a third, virtual, camera that has its own viewpoint, camera parameters, and position in the world coordinate system. This view has a texture that may be used as a default view, and also a corresponding disparity map. The disparity map provides depth information in systems where viewpoint adaptation is possible, and where it is not available the receiver is still provided with a realistic texture as an initial view.

View combining using Incomplete 3D (left) and Intermediate View (right)

The problems of occlusion errors and holes that are associated with image warping arise during the generation of the intermediate view. These can be overcome by implementing a rendering technique that employs occlusion ordering, while holes can be filled using a hidden layer technique.

This study has been supported by the Federal Ministry of Education and Research under grant AK 002.

[1] E. Cooke, O. Schreer, B. Pasewaldt and P. Kauff, "Extension of incomplete 3D for arbitrary multi-view-synthesis", Proc. VMV'00, Saarbrücken, Germany, Nov. 2000.

Eddie Cooke (cooke@hhi.de)

Virtual Tourism – Streaming of 360° Panoramas

A new system for interactive streaming of high-resolution 360° panoramic views over the Internet is presented. The scene is represented very efficiently using MPEG-4 BIFS and is displayed at the client using the HHI 3D MPEG-4 player. Streaming of the data is controlled by user interaction, and the visible parts are transmitted with priority.

The Internet has provided us with the possibility of connecting and communicating with computers anywhere in the world. We can access a huge amount of information and can also provide our own information to the global web community.

Starting from simple text transmission, the rapid development of technology over the last decade has enabled the transmission of any kind of data, including images, graphics and video. These technological advances have triggered the development of a huge variety of new services, especially in the field of multimedia communication.

A particularly popular group of services, which we denote virtual tourism, is the ability to access and retrieve visual information about other places in the world and to virtually visit cities, sights, landscapes (even non-terrestrial ones), buildings, museums, etc. The simplest media for this purpose are images, but they are restricted to a predefined viewpoint and have no temporal dimension. Video (e.g. webcams, streaming) extends the temporal dimension at the cost of an increased data rate.

Fig. 1: Streaming of high-resolution 360° panoramas over the Internet

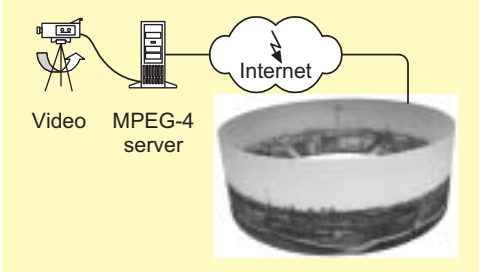
A highly attractive additional feature of such services is interactivity. The user should be given the maximum possible freedom to navigate within a scene (walk, rotate, zoom) and to choose his or her individually preferred views when exploring it. This requires new forms of representation of such scenes, e.g. the use of VRML to construct the virtual environments. Photo-realistic viewing requires the use of original textures.

Fig. 2: Rendered views from 360° panorama

The very popular QuickTimeVR® system is an example of such an application. It allows rotation and zoom within a 360° panoramic photo-realistic view. All information is downloaded completely before rendering in order to assure an acceptable reaction time of the system in an Internet scenario, so that the visual quality is quite bad (small images, low resolution).

We have launched a new project on virtual tourism [1] that aims to provide increased visual quality (by using high-resolution panoramic views) and to extend the navigation capabilities. The key idea is to stream the data (e.g. 1.8 Gbyte for a high-resolution panorama), and to display the images while still transmitting.

For this purpose we have developed a new scene representation that uses MPEG-4 BIFS. The panorama is divided into typically 100-200 patches. Each patch is encoded using JPEG2000. The actual view is displayed using the HHI 3D MPEG-4 player. Only those patches that are actually visible are displayed, which ensures efficient, fast and fluent rendering. As shown in Fig. 1, the panorama is generated from the video images captured by a rotating camera. The scene description is stored on an MPEG-4 server and can be accessed via the Internet.



At the client, the user navigates through the scene. An intelligent streaming mechanism ensures that only those patches that become visible over time are requested for transmission from the server.

[1] C. Grünheit, A. Smolic and T. Wiegand, "Interactive streaming of 3-D environments", project web page: http://bs.hhi.de/~smolic/3DStreaming.html.

Aljoscha Smolic (smolic@hhi.de)

High-Resolution Video Mosaicing

A new method for generating super-resolution mosaics from video is presented. The algorithm exploits the spatial alias of the video sequence to generate images and video with a higher resolution than the source video. Global warping parameters are estimated for every frame using a very accurate and robust algorithm. All frames are superimposed by warping towards a common reference image with double spatial resolution in both dimensions, avoiding any blending, averaging or interpolation of sub-pixel values. This preserves the original sharpness of the video and eliminates the spatial alias.

The process of video mosaicing denotes the transformation and blending of all images of a video sequence into a common reference coordinate system, as illustrated in Fig. 1. The result is a very compact representation of the visual content by a single static image. This is highly attractive for a variety of video processing applications. Such video mosaics are used for image-based rendering and the generation of virtual scenes and environments, and can be employed for video segmentation, coding, editing (e.g. stable replacement of parts of the background) and content description. Another application of high-resolution mosaics is in the up-sampling and format conversion of video signals.

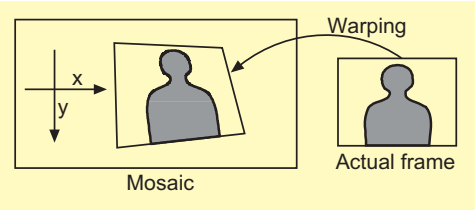


Fig. 1:
The mosaicing process: warping and blending all frames of a video sequence towards a common reference image

For some of these applications it is important that video mosaicing removes a significant amount of redundancy in the video signal, since information that is visible in several frames of the sequence is represented only once.

Alternatively, the redundancy of the video sequence can be exploited to extract additional visual information about the observed scene. For example, images and video with a higher spatial resolution than the original video can be produced by combining video mosaicing and super-resolution techniques [1].

Figure 2 illustrates the basic idea of our new algorithm. Global warping parameters are estimated for each frame using a very accurate and robust algorithm. All frames are superimposed by warping towards a common reference image with double spatial resolution in both dimensions, avoiding any blending, averaging or interpolation of sub-pixel values. This preserves the original sharpness of the video and eliminates the spatial alias. The method has been further extended to generate super-resolution video.

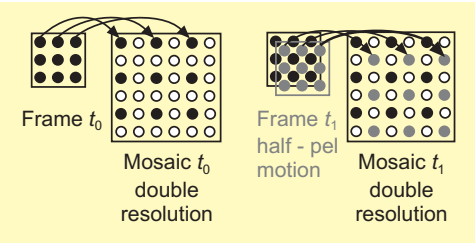


Fig. 2:
Transformation of video pixels into mosaic of double resolution, without interpolation of intermediate values

Figure 3 shows details from an original image (top) and a corresponding detail from a high-resolution mosaic (bottom). The high-resolution mosaic clearly provides superior visual quality – it is much sharper, has much more detail, appears less blocky, and most of all, aliasing is greatly reduced. This results in a reduction of annoying flicker effects in a video sequence of high-resolution mosaics.

Fig. 3:
Detail from original frame (top). Corresponding detail from high-resolution mosaic (bottom).

This work was supported by the Deutsche Forschungsgemeinschaft (DFG) under grant OH 50/8-1.

[1] A. Smolic and T. Wiegand, “High-resolution video mosaicing”, Proc. ICIP ’2001, Thessaloniki, Greece, 7-10 October 2001.

Aljoscha Smolic (smolic@hhi.de)

PUBLICATIONS*

Photonic Networks

H.-G. Bach, W. Schlaak, G. G. Mekonnen, R. Steingrüber, A. Seeger, W. Passenberg, W. Ebert, G. Jacumeit, Th. Eckhard, R. Ziegler, A. Beling, B. Schmauß[1], A. Munk[1], Th. Engel[2], A. Umbach[3], **50 GHz photoreceiver moules for RZ and NRZ modulation format comprising InP-OEICs**, 27th Europ. Conf. on Optical Communication (ECOC 2001), Amsterdam (NL), Th.M.2.5, pp. 560-561.

H.-G. Bach, **40 Gbit/s Photoempfänger für die hochratige Glasfaser-Telekommunikation (40 Gbit/s photoreceiver for a high-bit rate fiber optics communication)**, 10. Fachtagung VDE-GMM "Optische und elektronische Verbindungstechnik", München (D), 2001, Fachbereich 34, pp. 65-70.

E.-J. Bachus, R. Freund, M. Malach, E. Schulze, **Distributed Raman amplification in cascaded normilized sections: Modelling and 10 Gb/s transmission over 900 km without EDFAs**, Proc. 2. ITG-Fachtagung Photonische Netze, Dresden (D), 2001, pp. 133-134.

S. Bauer, O. Brox, C. Bornholdt, B. Sartorius, M. Moehrle, **Laser based 3 R regeneration for high-speed all-optical networks**, Proc. 2nd International Workshop on All-Optical Networks (WAON 2001), Zagreb (Croatia), pp. 59-61.

A. Beling, D. Schmidt, H.-G. Bach, G. G. Mekonnen, R. Ziegler, V. Eisner, M. Stollberg, G. Jacumeit, E. Gottwald, C.-J. Weiske, A. Umbach, **High power 1550 nm twin-photodetector modules with 45 GHz bandwidth based on InP**, Conf. Optical Fiber Communication (OFC 2002), Anaheim (CA, USA) March 17-22, 2002, accepted.

C. Bornholdt, S. Bauer, M. Möhrle, H.-P. Nolting, B. Sartorius, **All optical clock recovery at 80 GHz and beyond**, Proc. 27th Europ. Conf. on Optical Communications (ECOC 2001), Amsterdam (NL), p. 502.

R. Brunner[4], J. Bischoff[4], K. Rudolf[4], M. Ferstl, **Diffractive solid immersion lenses: characterization and manufacturing**, Proc. SPIEs 46th Annual Meeting on "Optical Science and Technology" San Diego, (USA), 2001, vol. 4449, pp. 235-243.

F. Buchali[5], W. Baumert[5], H. Bülow[5], U. Feiste, R. Ludwig, H. G. Weber, **Eye monitoring in a 160 Gbit/s RZ field transmission system**, Proc. 27th Europ. Conf. on Optical Communications (ECOC 2001), Amsterdam (NL), postdeadline paper.

B. Cai[6], T. Hattori[6], H. H. Deng[6], K. Komatsu[6], C. Zawadzki, N. Keil, T. Kaino[6], **Refractive index control and grating fabrication of DAST crystal**, J. Appl. Phys., (2001), vol. 40, part 2, no. 9A/B, pp. L964-L966.

C. Caspar, **Dispersion management for transparent WDM long distance networks**, Proc. 2. ITG-Fachtagung Photonische Netze, Dresden, (D), 2001, pp. 179-183.

C. Caspar, **Guidelines for a simplified design of reliable transparent optical networks**, AEP-Sonderheft, 2001, vol. 55, no. 5, pp. 363-367.

F. Devaux[7], O. Leclerc[7], B. Lavigne[7], H.-P. Nolting, B. Sartorius, **Alcatel-HHI collaboration on all-optical 3R regeneration**, Alcatel Telecom Review 3rd Quarter, June 2001, pp. 231-233.

D. Dias[8], S. Stankovic[8], H. Haidner[9], L. L. Wang[10], T. Tschudi[8], M. Ferstl, R. Steingrüber, **High frequency gratings for applications to DVD pickup systems**, J. Opt. A: pure Appl. Opt. vol. 3, no. 3, 2001, pp. 164-173.

C. Dreyer[11], M. Bauer[11], J. Bauer[11], N. Keil, H. H. Yao, C. Zawadzki, **Polycyanurate ester resins with low loss and low birefringence for use in integrated optics**, SPIE Conf. on "Linear and Non-Linear Optics of Organic Materials", San Diego (USA), 2001, Conf. Dig. p. 4461.

C. Dreyer[11], M. Bauer[11], J. Bauer[11], N. Keil, H. H. Yao, C. Zawadzki, **Polycyanurate ester resins with low loss for use in integrated optics**, Polytronic 2001, Potsdam (D), Conf. Dig. pp. 276-283.

H. Ehlers, M. Schlak, U. Fischer, **Packaging of integrated Mach-Zehnder interferometers for optical communication systems**, Conf. Optical Fiber Communication (OFC

* If titles are given bilingually the communication is in German. The list of footnotes is on page 116.

2001), Anaheim (USA), poster session 2 WDD66-1.

U. Feiste, R. Ludwig, C. Schubert, J. Berger, C. Schmidt, H. G. Weber, B. Schmauss[1], A. Munk[1], B. Buchold[1], D. Briggmann[12], F. Kueppers[12], F. Rumpf[12], **160 Gbit/s field transmission over 116km standard single mode fiber using 160 Gbit/s OTDM and 40 Gbit/s ETDM demultiplexer**, IEE Proc. Optoelectronics, vol. 148, no. 4, 2001.

U. Feiste, R. Ludwig, C. Schubert, J. Berger, C. Schmidt, H. G. Weber, B. Schmauss[1], A. Munk[1], B. Buchold[1], D. Briggmann[12], F. Kueppers[12], F. Rumpf[12], **160 Gbit/s transmission over 116 km field-installed fiber using 160 Gbit/s OTDM and 40 Gbit/s ETDM-technique**, Electron. Lett., vol. 37, no. 7, 2001, pp. 443-445.

M. Ferstl, **High selective etching of deep silica components using electron cyclotron resonance plasma**, Intern. Conf. on Micro- and Nano-Engineering (MNE), Grenoble (F), 2001, in press.

M. Gunkel[12], F. Küppers[12], J. Berger, U. Feiste, R. Ludwig, C. Schubert, C. Schmidt, H. G. Weber, **Unrepeatered transmission of 40 Gbit/s RZ over 252 km SMF using Raman amplification**, Electr. Lett., vol. 37, no. 10, 2001, pp. 646-648.

H. Heidrich, **Analysis of optical crosstalk within opto-electronic integrated circuits including lasers and photodetectors**, Proc. 10th European Conference on Integrated Optics (ECIO 2001), Paderborn (D), pp. 415-418.

H. Heidrich, R. Kaiser, P. Albrecht, S. Fidorra, M. Hamacher, W. Rehbein, **Analysis of optical crosstalk within opto-electronic integrated circuits including lasers and photodetectors**, Appl. Phys., vol. B73, 2001, pp. 581-583.

H. Heidrich, **Monolithically integrated photonic and optoelectronic circuits based on InP – technology, system applications, perspectives –**, Springer special Issue on Workshop "Microsystem Technologies" (Dortmund, June 2001).

E. Hilliger, J. Berger, H. G. Weber, K. Yvind[13], P. M. W. Skovgaard[13], J. Hanberg, **The cascaded amplifier and saturable absorber (CASA) all-optical switch**, Proc. OSA-Konferenz Photonics in Switching 2001, Monterey (CA, USA), June 10-14, 2001.

K. Janiak, U. Niggebrügge, **Investigation of macroscopic uniformity during CH4/H2 reactive ion etching of InP and its improvement by use of a guard ring**, J. of Vac. Sci. Technol. B 20(1), 2002, in press.

C. Janke[14], P. Haring[14], H. Künzel, H. Kurz[14], **Increased THz emitter efficiency by coherent superposition in a high repetition rate resonator**, Proc. Conf. on Lasers and Electro-Optics (CLEO/QELS), Baltimore (USA), May 2001, Techn. Dig., in press.

L. A. Jiang[15], E. P. Ippen[15], U. Feiste, S. Diez, E. Hilliger, U. Feiste, J. Berger, R. Ludwig, H. G. Weber, **Sampling pulses with semiconductor optical amplifiers**, IEEE Journal of Quantum Electronics, vol. 37, no. 1, pp. 118-126.

R. Kaiser, **OEICs/PICs Based on InP between technological faesibility and commercial success**, 13th Intern. Conf. on Indium Phosphide and Related Materials (IPRM 2001), Nara (J), invited short course.

N. Keil, H. H. Yao, C. Zawadzki, J. Bauer[11], M. Bauer[11], C. Dreyer[11], **Athermal polarisation-independent arrayed waveguide grating multiplexer using an all-polymer approach**, Appl. Phys. B73, (2001), 5-6 (special issue on Integrated Optics), pp. 619-622.

N. Keil, H. H. Yao, C. Zawadzki, J. Bauer[11], M. Bauer[11], C. Dreyer[11], **Athermal all-polymer arrayed waveguide grating multiplexer**, Electron. Lett. (2001), vol. 37, no. 9, pp. 579-580.

N. Keil, H. H. Yao, C. Zawadzki, J. Bauer[11], M. Bauer[11], C. Dreyer[11], **Athermal polarisation-independent all-polymer arrayed waveguide grating (AWG) multi/demultiplexer**, Conf. Optical Fiber Communication (OFC 2001), Anaheim (USA), postdeadline paper, Conf. Dig., PD7.

N. Keil, H. H. Yao, C. Zawadzki, J. Bauer[11], M. Bauer[11], C. Dreyer[11], J. Schneider[11], **Athermal polarisation-independent arrayed-waveguide grating (AWG) multiplexer using an all-polymer approach**, 10th Europ. Conf. on Integrated Optics (ECIO 2001), Paderborn (D), postdeadline-paper.

N. Keil, H. H. Yao, C. Zawadzki, K. Lösch[5], K. Satzke[5], W. Wischmann[5], J. v. Wirth[5], J. Schneider[11], J. Bauer[11], M. Bauer[11], **Hybrid polymer/silica vertical coupler switches**, Appl. Phys. B73, (special issue on Integrated Optics), (2001), 5-6, pp. 469-473.

N. Keil, H. H. Yao, C. Zawadzki, K. Lösch[5], K. Satzke[5], W. Wischmann[5], J. v. Wirth[5], J. Schneider[11], J. Bauer[11], M. Bauer[11], **Hybrid polymer/silica vertical coupler switches**, 10th Europ. Conf. on Integrated Optics (ECIO 2001), Paderborn (D), Conf. Dig., pp. 164-167.

J. Kreissl, U. Troppenz, W. Rehbein, B. Hüttl, E. Lenz, H. Venghaus, **High single-mode-yield multiple-wavelength DFB-laser arrays in the 1.55 µm range**, Proc. 27th Europ. Conf. on Optical Communications (ECOC 2001), Amsterdam (NL), Tu.B.1.1, pp.118.

K.-D. Langer, **KomNet – Transport- und Netztechniken für das Breitbandinternet (Optical transport and networking technologies for the broadband-internet)**, Proc. Consulting Akademie "Forum Optische Netze 2001", Königswinter (D), November 26-28, 2001.

K.-D. Langer, **KomNet – optical transport and networking technologies for the broadband-internet**, Proc. 2. ITG-Fachtagung Photonische Netze, Dresden (D), 2001, pp. 45-54.

K.-D. Langer, **KomNet – optical transport and networking technologies for the broadband-internet**, Proc. Intern. Conf. on Transparent Optical Networks (ICTON 2001), Krakau (PL), pp. 183-190.

G. Levy-Yurista[16], A. A. Friesem[16], E. Pawlowski, L. Küller, R. Ludwig, H. G. Weber, A. Donval[17], E. Toussaere[17], J. Zyss[17], **Hybrid semiconductor polymer resonant grating waveguide structures**, Optical Materials, 2001, vol. 17, pp. 149-154.

R. Ludwig, A. Sizmann[18], U. Feiste, C. Schubert, M. Kroh, C. M. Weinert, H. G. Weber, **Experimental verification of noise squeezing by an optical intensity filter in high-speed transmission**, Proc. 27th Europ. Conf. on Optical Communications (ECOC 2001), Amsterdam (NL), postdeadline paper.

K. Mantel[19], J. Lamprecht[19], R. Schreiner[19],N. Lindlein[19], J. Schwider[19], M. Ferstl, **Micro-cylinder-lens testing using computer-generated -holograms**, Fringe 2001, W. Osten and W. Jüptner (Eds.), Elsevier, Paris, 2001, pp. 100-105.

C. Möller, N. A. Maleev[20], W. Passenberg, J. Böttcher, H. Künzel, A. V. Skharov[20], A. E. Zhukov[20], A. F. Tsatsulnikov[20], V. M. Ustinov[20], **Development of 1300 nm GaAs-based microcavity light emitting diodes**, Proc. Int. Symp. "Nanostructures: Physics and Technologies", St. Petersburg (RUS) 2001, p.163.

G. Nachtwei[21], A. Manolescu[21], N. Nestle[21], H. Künzel, **Bistable resistance in a ferromagnetic quantum hall system induced by exchange enhancement of the Zeeman energy**, Phys. Rev. B 63, 045306(8) (2000).

H.-P. Nolting, **All-optical signal processing devices for photonic networks: towards packet switching**, "New Trends in Optical Network Design and Modeling", Kluwer Academic Publishers, edited by Alexandros A. Stavdas, 2001, pp. 49-76.

H.-P. Nolting, **All-optical 3R-regeneration for OTDM-systems** (invited), Plenary Session at Contemporary Photonics Technology, Tokyo International Forum, Yurakucho, Tokyo (J) 2002, pp. 15-18.

H.-P. Nolting, **Devices for 3R signal regeneration at 160 Gbit/s and faster** (invited), Proc. Workshop on Optical Signal Processing, Organized by COST 267, at COM, Technical University of Denmark, Lyngby, 2001, pp. 19-22.

H.-P. Nolting, H.-J. Wünsche[22], **Novel ultra high speed switching technique for all-optical signal processing**, Integrated Photonics Research (IPR 2001), Monterey (CA, USA), postdeadline paper PDP 1.

L. K. Oxenloewe[13], E. Hilliger, A. Tersigni[13], A. M. Nik[13], S. Hoejfeldt[13], F. Romstad[13], K. Yvind[13], P. M. W. Skovgaard[13], K. Hoppe[23], J. Hanberg[23], **All-optical demultiplexing and wavelength conversion in an electroabsorption modulator**, Proc. 27th Europ. Conf. on Optical Communications (ECOC 2001), Amsterdam (NL).

L. K. Oxenlowe[13], C. Schubert, C. Schmidt,

E. Hilliger, J. Berger, U. Feiste, R. Ludwig, H. G. Weber, **Optical clock recovery employing an optical PLL using cross-phase modulation in a Sagnac-interferometer**, Proc. Conf. on Lasers and Electro-Optics (CLEO 2001), Baltimore (USA), Tech. Dig., paper CThU2.

A. Paraskevopoulos, H.-J. Hensel, W. Molzow, K. Janiak, E. Suryaputra, H. Roehle, P. Wolfram, W. Ebert, **Fabrication of InGaAsP/InP ridge waveguide lasers with dry etched facets using chemically assisted ion beam etching and a simple photoresist mask**, Proc. LEOS 2001 annual meeting, La Jolla (USA), paper, TuE 4.

K. Pfeiffer[24], M. Fink[24], G. Ahrens[24], G. Gruetzner, F. Reuther[24], J. Seekamp[25], S. Zankovych[25], C. M. Sotomayor Torres[25], H. Schulz[25], H.-C. Scheer[25], R. Steingrüber, **Polymer stamps for nanoimprinting**, Intern. Conf. on Micro- and Nanoengineering (MNE 2001), Grenoble (F), in press.

D. Rabus, **Resonance frequency tuning of a double ring resonator in GaInAsP/InP: Experiment and simulation**, Special Issue on Indium Phosphide and Related Materials in JJAP, Part 1, vol. 41, no. 2, 2002.

D. Rabus, M. Hamacher, **MMI-coupled ring resonators on GaInAsP-InP**, IEEE Photonics Technology Letters, vol. 13, no. 8, 2001, pp. 812-814.

D. Rabus, M. Hamacher, **Optical filter and laser applications using micro ring resonators**, Second Online Symposium for Electronic Engineers (OSEE), sequence number B-93.

D. Rabus, M. Hamacher, H. Heidrich, **Active and passive microring resonator filter applications on GaInAsP/InP**, Proc. 13th Intern. Conf. on Indium Phosphide and Related Materials (IPRM 2001), Nara (J) pp. 477-480.

M. Rohde, **HF-control modulation for performance monitoring of WDM-networks**, Proc. 2. ITG-Fachtagung Photonische Netze, Dresden (D), 2001, pp. 165-168.

H. Rosenfeldt[26], Ch. Knothe[26], E. Brinkmeyer[26], R. Ulrich[26], U. Feiste, C. Schubert, J. Berger, R. Ludwig, H. G. Weber, A. Ehrhardt, **Automatic PMD compensation at 40 Gbit/s and 80 Gbit/s using a DOP-based feedback signal**, Proc. Optical Fiber Communication (OFC 2001), Anaheim (CA, USA), postdeadline paper PD27.

H. Rosenfeldt[26], R. Ulrich[26], E. Brinkmeyer[26], U. Feiste, C. Schubert, J. Berger, R. Ludwig, H. G. Weber, A. Ehrhardt[27], **Feed-forward approach for automatic PMD-compensation at 80 Gbit/s over 45 km. installed single mode fiber**, Proc. 27th Europ. Conf. on Optical Communications (ECOC 2001), Amsterdam (NL), postdeadline paper.

J. Saniter, V. Kravcenko, H. Feng, E. Patzak, **TransiNet – Innovative transport networks for the broadband internet**, Proc. 2. ITG-Fachtagung Photonische Netze, (jointly with TU-München, T-Systems Nova, Universität Stuttgart and TU-Berlin) Dresden (D), 2001, pp. 23-31.

B. Sartorius, **3R all-optical signal regeneration**, Proc. 27th Europ. Conf. on Optical Communications (ECOC 2001), Amsterdam (NL), September 30 - October 4, 2001, tutorial.

B. Sartorius, C. Bornholdt, S. Bauer, M. Möhrle, **40 GHz optical clock recovery for application in asynchronous networks**, Proc. 27th Europ. Conf. on Optical Communications (ECOC 2001), Amsterdam (NL), p. 442.

B. Schauwecker[28], M. Arnold[28], C. Radehaus[28], G. Przyrembel, B. Kuhlow, **Opical waveguide components with high refractive index difference in silicon-oxynitride for application in integrated optoelectronics**, Opt. Engineering vol. 41 (1), 2002, pp. 237-243.

C. Schubert, S. Diez. J. Berger, R. Ludwig, U. Feiste, H. G. Weber, G. Toptchiyski[29], K. Petermann[29], V. Krajinovic[30], **160 Gb/s all-optical demultiplexing using a gain-transparent ultrafast-nonlinear interferometer (GT-UNI)**, IEEE Photon. Techn. Lett., vol. 13, no. 5, 2001, pp. 475-477.

C. Schubert, J. Berger, U. Feiste, R. Ludwig, C. Schmidt, H. G. Weber, **160 Gb/s polarization insensitive all-optical demultiplexing using a gain-transparent ultrafast-nonlinear interferometer (GT-UNI)**, Techn. Dig. of Optical Amplifiers and their Applications (OAA 2001), Stresa (I), paper OWA4.

C. Schubert, J. Berger, U. Feiste, R. Ludwig, C. Schmidt, H. G. Weber, **160 Gb/s polarization insensitive all-optical demultiplexing using a gain-transparent ultrafast-nonlinear interferometer (GT-UNI)**, IEEE Photon. Techn. Lett., vol. 13, no. 11, 2001, pp. 1200-1202.

C. Schubert, J. Berger, E. Hilliger, H. G. Weber, G. Toptchyski[29], S. Randel[29], K. Petermann[29], **All-optical switching using gain-transparent semiconductor optical amplifiers**, In: Nonlinear Guided Waves and Their Applications, OSA Technical Digest, Washington, USA), 2001, pp. 23-25.

E. Schulze, R. Freund, M. Malach, F. Raub, **10 Gb/s NRZ transmission over 1800 km multiple pumed distributed Raman amplified transmission link without lumped amplifiers**, Proc. 27th Europ. Conf. on Optical Communications (ECOC 2001), Amsterdam (NL), vol. 2, pp. 160-161.

S. Stankovic[8], D. Dias[8], M. Hain[8], S. Bhattacharya[8], R. Glöckner[8], C. Karaboue[8], L. Benmohammadi[8], F. Guessous[8], T. Tschudi[8], L. Wang[10], M. Ferstl, E. Pawlowski, R. Steingrüber, **Integrated optical pickup system for axial dual focus**, Appl. Opt., vol. 40, no. 5, (2001), pp. 614-621.

R. Steingrüber, M. Ferstl, W. Pilz[31], **Micro-optical elements fabricated by electron-beam lithography and dry etching technique using top conductive coatings**, Microelectronic Engineering 57-58, Elsevier (2001), pp. 285-289.

R. Steingrüber, M. Möhrle, A. Sigmund, W. Fürst, **Continuously chirped gratings for DFB-lasers fabricated by direct write electron-beam lithography**, Intern. Conf. on Micro- and Nanoengineering (MNE), Grenoble (F), September 16-19, 2001, in press.

T. Tekin, **All-optical demultiplexing performance of monolithically integrated GS-MZI module**, Intern. Workshop on Optical MEMS and Integrated Optics 2001, Dortmund (D).

T. Tekin, M. Schlak, W. Brinker, J. Berger, C. Schubert, B. Maul, R. Molt, **All-optical demultiplexing using monolithically integrated Mach-Zehnder interferometer based on band gap shifted semiconductor optical amplifier**, Proc. 10th Europ. Conf. on Integrated Optics (ECIO 2001), Paderborn (D), postdeadline paper.

T. Tekin, M. Schlak, W. Brinker, J. Berger, C. Schubert, B. Maul, R. Molt, **Ultrafast all-optical demuliplexing performance of monolithically integrated band gap shifted Mach-Zehnder interferometer**, Proc. 27th Europ. Conf. on Optical Communications (ECOC 2001), Amsterdam (NL), vol. 4, pp. 504-505.

A. Umbach[32], **µm-wave photoreceivers and optoelectronic integrated circuits (OEICs)**, invited, International Microwave Sym. (IMS 2001) Workshop on Microwave Photonic Components, Phoenix (USA), in press.

H. Venghaus, **Optoelektronische und optische Bauelemente und Schaltungen (Photonic integrated devices and circuits)**, Handbuch für die Telekommunikation, Jung, Warnecke (Hrsg.), Springer, 2. Auflage.

B. V. Volovik[20], A. R. Kovsh[20], W. Passenberg, H. Künzel, N. Grote, N. A. Cherkashin[20], Yu.G. Musikhin[20], N. N. Ledentsov[29], D. Bimberg[29], V. M. Ustinov[20], **Optical and structural properties of self-organized InGaAsN/GaAs nanostructures**, Sem.Sci. Techn. 16, 186 (2001).

G. Walf, **KomNet – Scope and recent accomplishments**, Proc. 27th Europ. Conf. on Optical Communications (ECOC 2001), Amsterdam (NL), p. 36.

H. G. Weber, R. Ludwig, U. Feiste, C. Schmidt, E. Hilliger, C. Schubert, J. Berger, M. Kroh, T. Yamamoto, **Optical signal processing for high speed communication systems** (invited), Proc. 10th European Conference on Integrated Optics (ECIO 2001), Paderborn (D), 2001.

C. M. Weinert, J. Berger, U. Feiste, E. Hilliger, B. Konrad[29], M. Kroh, R. Ludwig, K. Petermann[29], C. Schmidt, C. Schubert, H. G. Weber, T. Yamamoto[33], **High bit rate OTDM-transmission on standard fibre**, Archiv für Elektronik und Übertragungstechnik (AEÜ), dedicated to Professor Voges on the occasion of his 60th birthday, 1997, Gustav Fischer Verlag, Jena.

C. M. Weinert, A. Sizmann[18], R. Ludwig, C. Schubert, U. Feiste, H. G. Weber,

N**onlinear optical intensity filters: Experiment and design rules**, Proc. 27th Europ. Conf. on Optical Communications (ECOC 2001), Amsterdam (NL), pp. 274-275.

H.-J. Wünsche[22], M. Radzunias[22], H.-P. Nolting, **Modeling of devices for all-optical 3R-regeneration** (invited), Proc. Integrated Photonics Research (IPR 2001), Monterey (CA, USA), pp. IWA1-3.

T. Yamamoto[33], U. Feiste, J. Berger, C. Schubert, C. Schmidt, R. Ludwig, H. G. Weber, **160 Gbit/s demultiplexer with clock recovery using SOA-based interferometric switches and ist application to 120 km fiber transmission**, Proc. 27th Europ. Conf. on Optical Communications (ECOC 2001), Amsterdam (NL), pp. 192-193.

T. Yamamoto[33], C. Schubert, C. Schmidt, L. K. Oxenlowe[13], U. Feiste, H. G. Weber, **A semiconductor laser amplifier in a loop mirror as a phase comparator in PLL-based clock recovery for 160 Gb/s data signals**, Techn. Dig. Of Optical Amplifiers and their Applications (OAA 2001), Stresa (I), paper OTuC2, 2001.

T. Yamamoto[33], L. K. Oxenlowe[13], C. Schmidt, C. Schubert, E. Hilliger, U. Feiste, J. Berger, **Clock recovery from 160 Gb/s data signals using a phase-locked loop with an interferometric optical switch based on a semiconductor optical amplifier**, Electron. Lett., vol. 37, no. 8, 2001, pp. 509-510.

H. H. Yao, N. Keil, C. Zawadzki, K. Lösch[5], K. Satzke[5], W. Wischmann[5], J. v. Wirth[5], J. Schneider[11], J. Bauer[11], M. Bauer[11], **Polymeric planar waveguide devices for photonic network applications** (invited), SPIE Conf. on Design, Manufacturing, and Testing of Planar Optical Waveguide Devices, San Diego (USA) 2001, Conf. Dig., p. 4439.

H. H. Yao ,N. Keil, C. Zawadzki, M. Bauer[11], J. Bauer[11], C. Dreyer[11], J. Schneider[11], **Polymeric waveguide devices for DWDM applications**, 10th Intern. Plastic Optic Fibres Conf. (POF 2001), Amsterdam (NL), Conf. Dig., pp. 139-146.

H. H. Yao, N. Keil, C. Zawadzki, K. Lösch[5], K. Satzke[5], W. Wischmann[5], J. v. Wirth[5], J. Schneider[11], J. Bauer[11], M. Bauer[11], **Integrated thermo-optic switches in silica/polymer waveguide technology** (invited), SPIE Conf. on Materials and Devices for Photonics Circuits, San Diego (USA), 2001, Conf. Dig., p. 4453.

Mobile Broadband Systems

H. Boche, E. Jugl[1], **Review of Viterbi's model estimating the capacity of CDMA based mobile systems**, IEICE Trans. on Communications, vol. E84-B, no. 12, 2001, pp. 3212-2117.

H. Boche, M. Protzmann[34], **Oversampling and boundation of signals**, IEEE Trans. on Circuits and Systems-I: Fundamental Theory an Applications, vol. 48, no. 3, 2001, pp. 364-365.

H. Boche, G. Wunder, **Analytical methods for estimating the statistical distribution of the crest-factor in OFDM systems**, Proc. 10th Aachen Symp. on Signal Theory, 2001, Aachen (D), pp. 223-228.

H. Boche, M. Schubert, **A new approach to power adjustment for spatial covariance based downlink beamforming**, ICASSP 2001, Salt Lake City, Utah (USA), vol. V SAM-P3.

H. Boche, M. Schubert, **Theoretical and experimental comparison of optimisation criteria for downlink beamforming**, European Transactions on Telecommunications, Special Issue on Smart Antennas, 2001, vol. 12, no. 5, pp. 417-426.

H. Boche, S. Stanczak, **Lower bound on mean squared channel estimation error for multiuser receiver**, ISCAS 2001, Sydney (AUS), II-61-II-64.

H. Boche, S. Stanczak, **Optimal sequences for asynchronous CDMA channels with different SIR requirements**, Proc. 35th Asilomar Conf. on Signals, Systems, and Computers, 2001, Pacific Grove, CA (USA), pp. 415-419.

H. Boche, G. Wunder, **Analytical methods for estimating the statistical distribution of the crest-factor in OFDM systems**, Proc. 10th Aachen Symp. on Signal Theory, 2001, Aachen (D), pp. 223-228.

H. Boche, G. Wunder, **On the PAPR problem in OFDM systems** (invited paper), 39th Annual Allerton Conference on Communica-

tion, Allerton (IL, USA), Control, and Computing, 2001, in press.

G. Grosskopf, R. Eggemann, D. Rohde, M. S. Choi, **155 Mbits data transmission at 60 GHz using a 1 x 4 patch array antenna with variable optical delay lines**, Proc. IEEE MTT-S Intern. Microwave Symp., Phoenix, Arizona, USA, 2001, Digest vol. 3, paper TH3D-5, pp. 1821-1824.

G. Grosskopf, B. Kuhlow, G. Przyrembel, R. Eggemann, J. Knueppel, D. Rohde, **Silica based beamformer for 60 GHz smart antennas**, 27th European Conf. on Optical Communication (ECOC 2001), Amsterdam (NL), vol. 1, paper Mo. F2.6, pp. 12-13.

G. Grosskopf, D. Rohde, A. Kortke, R. Eggemann, R. Ziegler, M. S. Choi, **155 Mbit/s Datenübertragung im 60 GHz-Bereich mit einer optisch gesteuerten Array Antenne (155 Mbit/s data transmission at 60 GHz using an optically steered array antenna)**, Proc. ITG-Diskussionssitzung "Systeme mit intelligenten Antennen" 2001, TU Ilmenau (D).

T. Haustein, E. Jorswieck, V. Jungnickel, U. Krueger, V. Pohl, C. v. Helmolt, **Bit error rates for a mimo system in Rayleigh and Rician channels**, IEEE 54rd Vehicular Technology Conference, 2001, Atlantic City (NJ, USA), vol. 4, pp. 1984-1987.

M. Haardt[35], H. Boche, G. Wunder, **The future of mobile communications beyond the third generation**, 30. Annual IEEE Comm.-Theory Workshop, San Diego (USA), April 2001.

A. Ihlow[36], H. Boche, **Kapazitätsgewinn durch SDMA mit linearen Antennenarrays in realer Umgebung (Capacity gain via SDMA with linear antenna arrays in real environments)**, Proc. ITG-Diskussionssitzung "Systeme mit intelligenten Antennen" 2001, Ilmenau (D).

E. Jorswieck, G. Wunder, V. Jungnickel, T. Haustein, **Eigenvalue and inverse eigenvalue statistics for Rayleigh and Rician MIMO channels**, Proc. IEE Colloquium on MIMO Communication Systems, 2001, London (GB) pp. 3/1-3/6.

V. Jungnickel, A. Forck, T. Haustein, U. Krüger, V. Pohl, C. v. Helmolt, **Wireless infrared communications beyond 100 Mbit/s: system design, transmission experiments and potential**, (invited), Proc. 5th World Multiconference on Systemics, Cybernetics and Informatics 2001, Orlando (FL, USA), vol. IV, pp. 413-420.

V. Jungnickel, T. Haustein, A. Forck, C. v. Helmolt, **155 Mbit/s wireless transmission with an imaging infrared receiver**, IEE Electronics Letters, vol. 37, no. 5, (2001), pp. 314-315.

V. Jungnickel, T. Haustein, E. Jorswieck, C. v. Helmolt, **A MIMO WLAN based on linear channel inversion**, Proc. IEE Colloquium on MIMO Communication Systems: From Concept to Implementation, London (GB), 2001, pp. 20/1-20/6.

V. Jungnickel, T. Haustein, E. Jorswieck, V. Pohl, C. v. Helmolt, **Performance of a MIMO system with overlay pilots**, IEEE GlobeCom 2001, San Antonio (Texas), on CD-ROM.

V. Jungnickel, V. Pohl, U. Krüger, C. v. Helmolt, T. Haustein, S. Stanczak, **A radio system with multi-element antennas**, Proc. IEEE 53rd Vehicular Technology Conference, 2001, Rhodos (GR), on CD-ROM.

V. Kravcenko, H. Boche, E. Jugl, **Models for BER estimation of CDMA-systems and sequences design**, Proc. 10th Aachen Symp. on Signal Theory, 2001, Aachen (D), pp. 275-280.

U. Krüger, C. v. Helmolt, V. Jungnickel, T. Haustein, **A power and bandwidth efficient modulation for diffuse wireless infrared communication**, Journal of Optical Communication, vol. 22 (2001), pp. 721-723.

V. Pohl, V. Jungnickel, U. Krüger, C. v. Helmolt, **Integrating sphere diffuser for wireless infrared communication**, IEE Photonics Professional Network, available online at www. iee.org.uk.

D. Rohde, A. Kortke, R. Ziegler, R. Eggemann, G. Grosskopf, M. S. Choi, **Optically steered 1x4 patch array antenna for 60 GHz**, Proc. Microwaves and Optronics, 11th The German Wireless Week (MIOP'2001), Sindelfingen (D), pp. 128ff.

M. Schubert, H. Boche, **Leistungsoptimier-**

tes Downlink-Beamforming für zellulare Mobilfunksysteme (Power optimized downlink beamforming for cellular wireless systems), Proc. ITG-Diskussionssitzung "Antennen für Mobile Systeme 2001", Ilmenau (D), pp. 113-122.

M. Schubert, H. Boche, **CIR-based multiuser downlink beamforming**, Proc. 10th Aachen Symp. on Signal Theory, Aachen (D), 2001, pp. 237-242.

M. Schubert, H. Boche, **Solvability of coupled downlink beamforming problems**, Proc. IEEE Globecom Conf., San Antonio, Texas, 2001, BWS06-2.

S. Stanczak, H. Boche, M. Haardt[35], **Are LAS-codes a miracle?**, Proc. IEEE Globecom Conf., San Antonio, Texas, 2001, BWS05-4.

G. Wunder, H. Boche, **Trigonometric sampling series and their application to mobile communications**, Kleinheubacher Berichte, T-Nova Technologiezentrum, vol. 44, pp. 183-190.

G. Wunder, H. Boche, **Performance bounds and optimal pilot signals in OFDM-MIMO systems**, Proc. 10th Aachen Symp. on Signal Theory, 2001, Aachen (D), pp. 123-128.

Electronic Imaging Technology for Multimedia

C. Buchner, T. Stockhammer, D. Marpe, G. Blättermann, G. Heising, **Efficient fine granular scalable video coding**, Proc. IEEE Int. Conf. on Image Processing (ICIP 2001), Thessaloniki (GR), pp. 997-1000.

C. Buchner, T. Stockhammer, D. Marpe, G. Blättermann, G. Heising, **Progressive texture video coding**, Proc. Int. Conf. on Acoustics, Speech, and Signal Processing (ICASSP 2001), Salt Lake City, Utah (USA), in press.

R. Buss, U. Hambrock, **The effect of the perceived work situation and background knowledge on assessing people's willingness to communicate**, Proc. 18th Int. Symp. on Human Factors in Telecommunication (HFT 2001), Bergen (N), pp. 81-88.

C. Fehn, E. Cooke, O. Schreer, P. Kauff, **3D analysis and image-based rendering for immersive TV applications**, Proc. Int. Conf. on Augmented, Virtual Environments and 3D Imaging (ICAV3D 2001), Mykonos (GR), pp. 192-195.

C. Fehn, P. Kauff, R. Schäfer, **Interactive Virtual View Video – Eine Erweiterung des immersiven Fernsehens (Interactive virtual view video – An extension of immersive television)**, Proc.9. Dortmunder Fernsehseminars, Dortmund (D), 2001, pp. 163-168.

C. Fehn, P. Kauff, R. Schäfer, O. Schreer, **Interactive virtual view video for immersive TV applications**, Proc. IBC 2001, Amsterdam (NL), vol. 2, pp. 53-61.

B. Feustel, T. C. Schmidt, D. Marpe, M. Palkow, H. L. Cycon, **Compound media streaming in time**, Proc. 9th Int. Conf. in Central Europe on Computer Graphics, Visualization and Computer Vision (WSCG 2001), Univ. of West Bohemia, Plzen (Czech Rep.), pp. 161-167.

M. Hahn, C. Huck, **Digital projectors for videorepresentation**, FKT, vol. 55, no. 1-2, Febr. 2001, pp. 36-43.

P. Kauff, C. Fehn, E. Cooke, O. Schreer, **Advanced incomplete 3D representation of video objects using trilinear warping for novel view synthesis**, Proc. Picture Coding Symposium (PCS 2001), Seoul (Korea), pp. 429-432.

P. Kauff, O. Schreer, **An immersive 3D videoconferencing system based on a shared virtual environment**, Proc. of Int. Conf. on Media Futures, Florence (I) 2001, pp. 49-52.

P. Kauff, O. Schreer, J.-R. Ohm[14], **A universal algorithm for real-time estimation of dense displacement vector fields**, Proc. of Int. Conf. on Media Futures, Florence, (I) 2001, pp. 311-314.

I. Keller, T. Ellerbrock, T. Meiers, T. Sikora, **Fast user-adaptive weighting of MPEG7 descriptors for a visual E-commerce interface**, Proc. 3th European Workshop on Image Analysis for Multimedia Services (WIAMIS 2001), Tampere (SF), pp. 147-152.

I. Keller, T. Meiers, T. Ellerbrock, T. Sikora, **Image browsing with PCA-assisted user-interaction**, Proc. IEEE Workshop on Content-

based Access of Image and Video Libraries (CBAIVL 2001), (Kauai, HI, USA), pp. 102-108.

J. Liu, C. Conomis, Z. Zhu, S. Pastoor, **Real-time head tracking in multimodal interface with changes in geometry and illumination**, Proc. IASTED International Conference "Visualization, Imaging and Image Processing (VIIP 2001)", Marbella (E), pp. 608-612.

D. Marpe, G. Blättermann, G. Heising, T. Wiegand, **Video compression using context-based adaptive arithmetic coding**, Proc. IEEE Int. Conf. on Image Processing (ICIP 2001), Thessaloniki (GR), pp. 558-561.

D. Marpe, T. Wiegand, H. L. Cycon, **Wavelet-based video compression using long-term memory motion-compensated prediction and context-based adaptive arithmetic coding**, Lecture Notes on on Wavelet Analysis and Its Applications, Computer Science, Springer Verlag Berlin, vol. 2251, pp. 76-86.

T. Meiers, I. Keller, T. Sikora, **Image visualization and navigation based on MPEG-7 descriptors**, Proc. Intern. Conf. on Augmented, Virtual Environments and 3D Imaging (EUROIMAGE 2001), Mykonos (GR), pp. 165-168.

T. Meiers, I. Keller, T. Sikora, **3D browsing environment for MPEG-7 image databases**, Proc. IS&T/SPIE Workshop "Storage and Retrieval for Media Databases 2002", San José, CA (USA), pp. 324-335.

B. Quante, R. Buss, L. Mühlbach, D. Przewozny, D. Runde, **An experimental comparison of two variants of an informal communication module for distributed workgroups**, Proc. 18th Int. Symp. on Human Factors in Telecommunication (HFT 2001), Bergen (N), pp. 89-98.

J. Restat, **An inventory of terms for precise cognitive theories**, 5th Meeting of the German Cognitive Science Society, in: Leipzig Series in Cognitive Sciences 2, T. Arnold and Ch. S. Herrmann (Eds.), Leipziger Universitätsverlag, Leipzig (D), 2001, p. 73.

J. Restat, **Psychological relevant features of color patterns**, Proc. Workshop on Image Analysis for Multimedia Services (WIAMIS 2001), Tampere (SF), pp. 107-112.

H. Richter[37], A. Smolic, B. Stabernack, E. Müller, **Real time global motion estimation for an MPEG-4 video encoder**, Proc. Picture Coding Symposium (PCS 2001), Seoul (Korea), pp. 401-404 .

R. Schäfer et. al., **Kooperative Postproduktion von Film und Video in High-Speed Netzwerken (System for distributed post-production of video using a high-speed network)**, Proc. ITG/FKTG-Fachtagung, 9th Dortmunder Fernsehseminar, Dortmund (D), 2001, pp. 143-148.

R. Schäfer, T. Sikora, **Performance-Messung am HHI – Konzept und Erfahrungen (Performance-measurement in the HHI – draft and experiences)**, Wissenschafts management – Zeitschrift für Innovation, 7. Jahrgang (2001), Heft 8, pp. 11-16.

O. Schreer, N. Brandenburg, S. Askar, **A virtual 3D video-conference system providing semi-immersive telepresence: a real-time solution in hardware and software**, eBusiness 2001, Venice (I), vol. 1, pp. 184-190.

O. Schreer, N. Brandenburg, S. Askar, P. Kauff, **Hybrid recursive matching and segmentation-based postprocessing in real-time immersive video conferencing**, Vision, Modeling and Visualization, Stuttgart (D), 2001, pp. 383-390.

O. Schreer, N. Brandenburg, Peter Kauff, **A combination of census transform and a hybrid block and pixel-recursive disparity analysis approach for real-time videoconferencing applications**, Proc. Int. Conf. on Augmented, Virtual Environments and 3D Imaging (ICAV3D 2001), Mykonos (GR), pp. 29-32.

O. Schreer, N. Brandenburg, P. Kauff, **Real-time disparity analysis for applications in immersive tele-conference scenarios – a comparative study**, ICIAP 2001, Palermo (I), pp. 346-353.

O. Schreer, C. Fehn, N. Brandenburg, M. Karl, P. Kauff, **Fast disparity estimator for real-time video processing using a hybrid block- and pixel-recursive matching technique**, Proc. Picture Coding Symposium (PCS 2001), Seoul (Korea), pp. 405-409.

K. Seifert[29], J. Liu, J. Hurtienne, T. Baumgarten, S. Pastoor, **Development of an evaluation concept for a multimodal computer system**, Proc. 8th IFAC Symposium on Analysis, Design, and Evaluation of Human-Machine Systems, Gesamthochschule Kassel, 2001, in press.

K. Seifert[29], S. Pastoor, **Multimodal human-computer interaction: When the computer is watching us**, TU Berlin, Forschung Aktuell, 1/2001, Mensch und Maschine, pp. 82-83.

A. Smolic, **Global motion compensation and video mosaicing using different 2-D motion models**, Proc. Picture Coding Symposium (PCS '2001), Seoul (Korea), pp. 331-334.

A. Smolic, **Parametric motion models and video mosaics and their applications at coding, post-production and information management**, Proc. ITG/FKTG-Fachtagung, 9th Dortmunder Fernsehseminar, Dortmund (D), 2001, pp. 175-180.

Smolic, T. Wiegand, **High-resolution video mosaicing**, IEEE Intern. Conf. on Image Processing (ICIP '2001), Thessaloniki (GR), on CD-ROM.

E. Trucco, C. Plakas, N. Brandenburg, P. Kauff, M. Karl, O. Schreer, **Real-time disparity analysis for Immersive 3-D Teleconferencing by Hybrid Recursive Matching and Census Transform**, ICCV 2001, Vancouver (CDN), in press.

1 Lucent Technologies, Nürnberg, D
2 Siemens AG, Berlin, D
3 u2t Photonics AG, Berlin, D
4 Carl Zeiss, Jena, D
5 Alcatel, Stuttgart, D
6 Tohuku University, Sendai, J
7 Alcatel, Paris, F
8 Technical University Darmstadt, D
9 Carl Zeiss, Oberkochen, D
10 Philips Eindhoven, NL
11 Fraunhofer Institut (IZM), Berlin-Teltow, D
12 T-Nova – Deutsche Telekom, Darmstadt, D
13 Denmark Technical University, Kopenhagen, DK
14 RWTH Aachen, D
15 Institute of Technology, Massachusetts, USA
16 Weizmann Institute of Science, Rehovot, IL
17 Laboratoire de Photonique Quantique et Moleculaire, F
18 Innovance Networks Inc., CDN
19 University of Erlangen, D
20 Ioffe Institut, St. Petersburg, RUS
21 Technical University Braunschweig, D
22 Humboldt-University, Berlin, D
23 GiGA-Intel, DK
24 micro resist technology GmbH, Berlin, D
25 University of Wuppertal, D
26 Technical University Hamburg-Harburg, D
27 T-Nova, Berlin, D
28 Technical University Chemnitz, D
29 Technical University Berlin, D
30 Technical University Wien, A
31 ISIT, Itzehoe, D
32 u2t Photonics AG, Berlin, D
33 Fujitsu Laboratories Ldt., Wakamiya, J
34 Technical University Dresden, D
35 Siemens AG München, D
36 Technical University Ilmenau, D
37 University of Rostock, D

REPORTS

E.-J. Bachus, C. Caspar, M. Rohde, K. Habel, **System aspects and test of components for the cityring network**, Final Report on contract with T-Nova Deutsche Telekom AG, HHI, Berlin, January 2001.

T. Ellerbrock, **Bildinhaltserkennung und Segmentierung für Multimedia-Anwendungen (Recognition of image content and segmentation for multimedia applications)**, Final Report on DFG Research Project SE 456/5-1, HHI jointly with TU Berlin, August 2001.

G. Heising, D. Marpe, **Open issues relating to H.26L picture header**, ITU-T Study Group 16/Question 6 Document VCEG-M-62, Austin (USA), April 2001.

D. Marpe, G. Blättermann, G. Heising, T. Wiegand, **TML5 software including CABAC**, ITU-T Study Group 16/Question 6 Doc. VCEG-M-60, Austin (USA), April 2001.

D. Marpe, G. Blättermann, G. Heising, T. Wiegand, **Further results on CABAC entropy coding scheme**, ITU-T Study Group 16/Question 6 Doc. VCEG-M-59, Austin (USA), April 2001.

D. Marpe, G. Blättermann, T. Wiegand, **Improved CABAC**, ITU-T Study Group

16/Question 6 Doc. VCEG-O-18, Pattaya (Thailand), December 2001.

K. Mertens, **Investigations on Erbium-doped fibre amplifiers**, Report on a practical semester, HHI and TFH-Berlin, January 2001.

M. Rohde, **Controlling of WDM channels in photonic networks by means of control modulation**, Report on DFG Research Project Ba 1790/1-1 (WDMCONT), July 2001.

M. Schlak, **Final report DEMUX' Alcatel-HHI collaboration – All-optical signal processing**, May 2001.

M. Schubert, A. Kortke, H. Boche, **Space-time array processing for 3G WCDMA - channel modeling and directivity controlled beamforming**, Final Report, 2nd Year Collaborative Research ETRI/HHI, August 2001.

E. Schulze, **Influence of distributed Raman-amplification on high data rate WDM networks**, Final Report on DFG Research Project Ba 1790/2-1 (RAMAN), HHI, Berlin, July 2001.

A. Smolic, **Videocodierung unter Verwendung von 2D und 3D Objekt- und Bewegungsmodellen (Application of 2D and 3D object and motion models for video coding)**, Technical Report on DFG Research Project OH 50/8-1, September 2001.

A. Smolic, Y. Guo, J. Guether, T. Selinger, **Demonstration of streaming of MPEG-4 3-D scenes with live video**, ISO/IEC JTC1/SC29/WG11, M7811, December 2001.

T. Stockhammer, D. Marpe, **Test model document changes for data partitioning and NAL**, ITU-T Study Group 16/Question 6 Doc. VCEG-M-52, Austin (USA), April 2001.

T. Wiegand, K. Müller, H. Schwarz, **H.26L TML 8 for Digital Cinema Applications**, ISO/IEC JTC1/SC29/WG11 MPEG01, m7848, Pattaya, Thailand, December 2001.

PATENT APPLICATIONS

D. Rohde, G. Großkopf, A. Kortke, **Planarantennenmodul für Wellenlängen im Millimeterbereich (Millimeter-wave patch antenna module for V-band applications)**, 101 02 468.1-35

O. Schreer, P. Kauff, N. Brandenburg, M. Karl, **Verfahren zur Korrespondenzanalyse von Bildmerkmalen in korrespondierenden Videobildern in Echtzeit (Method for real-time correspondence analysis of image features in corresponding video images)**, 101 05 423.8-53

R. Stenzel, H. Roehle, H. Stolpe, **Probenhalter (Sample holder)**, 101 10 297.6-52

D. Brand, **Gasbündelstation mit Druckmindererstation und Sicherheitsabschaltung (Pressure reducing valve and safety shutdown in a bundle of gas cylinders)**, 201 03 682.7

N. Keil, H. Yao, C. Zawadzki, **Einstellbarer optischer Pegelangleicher (Active gain equalizer)**, 101 12 021.4-51

M. Rohde, E.-J. Bachus, K.-D. Langer, **Verfahren zur Qualitätsüberwachung und Identitätskontrolle von Wellenlängenkanälen sowie zur Übertragung von Netzmanagement-Informationen in transparenten optischen Übertragungsnetzen (Method for quality and identity monitoring of wavelength channels and for transport of network management information in transparent optical networks)**, 101 12 511.9-35

V. Jungnickel, V. Pohl, U. Krüger, C. v. Helmolt, Th. Haustein, S. Stanczak, **Funkübertragungsverfahren im Innenraumbereich zur parallelen Funkübertragung von digitalen Datenteilströmen und mobiles Funkübertragungssystem (Parallel radio transmission of cochannel signals in indoor environments and system for wireless data transmission)**, 101 14 052.5-35

W. Liebsch, D. Zier, **Elektronisches Verfahren zur zuschauerindividuellen Suche und Auswahl von Fernsehprogrammangeboten (Electronic procedure for viewer-individual search and selection of television program supplies)**, 101 18 966.4-31

H.-P. Nolting, M. Gravert, **Abstimmbarer, selbstpulsierender Zweisektions-Laser zur optischen Taktfrequenzerzeugung und dessen Verwendung (Tunable selfpulsat-**

ing multi-section-laser for clock recovery), 101 18 965.6-33

B. Sartorius, St. Bauer, C. Bornholdt, O. Brox, **Verfahren zur Ansteuerung eines Laser-basierenden 3R Regenerators (Scheme for the operation of a laser based 3 R regenerator)**, 101 18 959.1-35

B. Sartorius, **3R Regenerator mit Wellenlängenumsetzung (3R regenerator with wavelength conversion)**, 101 18 958.3-35

H. Heidrich, C. M. Weinert, **Integriert-optischer Feldweitentransformator zur adiabatischen, monomodigen Feldanpassung (Integrated optical beam spread transformer for adiabatic, single mode field adaptation)**, 101 23 137.7-51

D. Rohde, G. Großkopf, A. Kortke, **Planarantennenmodul für Wellenlängen im Millimeterbereich (Millimeter-wave patch antenna module for V-band applications)**, 101 23 571.2-35

M. Hamacher, H. Heidrich, M. Hentschel, D. G. Rabus, K. Richter, **Monolithisch integrierter Mikrolaser mit einem nur eine Spiegelebene aufweisenden Zirkularresonator (Monolithically integrated microlaser based on a circular resonator with only one mirror plane)**, 101 32 479.0-33

V. Jungnickel, Th. Haustein, E. Jorswieck, G. Wunder, U. Krüger, V. Pohl, C. v. Helmolt, **Adaptives Signalverarbeitungsverfahren zur bidirektionalen Funkübertragung in einem MIMO-Kanal und MIMO-System zur Verfahrensdurchführung (Adaptive bidirectional transmission in a MIMO radio channel and MIMO system for wireless data transmission)**, 101 32 492.8-35

H. Heidrich, M. Hamacher, D. G. Rabus, U. Troppenz, **Verfahren zum kraftschlüssigen Ganzwaferlöten (Process for force-fit full-wafer soldering)**, 101 53 054.4

R. Schmidt, **Schweißbacken für das Schutzgasschweißen von Rohrverbindungen mit Schweißfittingen aus Edelstahl (Welding jaw for orbital welding of stainless steel tube fittings)**, 201 19 625.5

S. Bauer, O. Brox, **Optische Mikrowellenquelle (Optical microwave source)**, 101 60 502.1

D. Brand, **Werkzeug zum Übertragen positiver oder negativer Drehmomente in engen Montageräumen (Tool to transform positive or negative torques in narry assembly sites)**, 101 62 112.4

J. Holzäpfel, **Entsorgungssystem für gefährliche Abfallflüssigkeiten an einem Laborarbeitsplatz (Disposal system for hazardous liquid waste at a laboratory workbench)**, 101 64 645.3

H.-P. Nolting, M. Gravert, **Verfahren zur Kontrolle und Steuerung der Datensynchronisation in einer Pulsquelle zur reinoptischen Taktrückgewinnung (Method for control of data synchronization process of an all-optical clockrecovery based on multi-section lasers)**, 101 64 644.5

H.-P. Nolting, **Verfahren zur direkten Qualitätsermittlung von optischen Übertragungskanälen und Anordnung zu dessen Durchführung (All-optical method for direct control of optical signal quality)**, 101 64 643.7

AWARDS

C. Fehn, P. Kauff, O. Schreer and R. Schaefer, **President's Award for Best Technical Paper at IBC '01**, International Broadcast Convention, Amsterdam, Sept. 2001.

DOCTORATE THESES

D. Runde, **Verzerrungsfreie Reproduktion räumlicher Szenen bei Bewegungen des Betrachters (A natural image reproduction using stereoscopic displays with motion parallax)**, TU Berlin, 2000, FB (12) Elektrotechnik, Prof. Boerger, Prof. Filbert.

A. Smolic, **Globale Bewegungsbeschreibung und Video Mosaiking unter Verwendung parametrischer 2-D Modelle, Schätzverfahren und Anwendungen (Description of global motion and video mosaicing applying parametric 2-D motion models, estimation and applications)**, Rheinisch-Westfälischen Technischen Hochschule Aachen (RWTH), Fakultät für Elektrotechnik und Informationstechnik, Prof. Ohm.

DIPLOMA THESES

U. Grabner, **Einbettung eines RISC-Kerns in einen Echtzeit-Video-Formatkonverter ASIC (Embedding of a RISC core into a real time video format conversion ASIC)**, TU Berlin, FB13 (Informatik). Supervisor at HHI: T. Weber.

I. Grotelüschen, **Analyse und Vergleich von Optimierungskriterien für die Downlink-Strahlformung in UMTS (TD/CDMA) (Analysis and comparison of optimization criteria for downlink beamforming in UMTS (TD/CDMA) systems)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: H. Boche.

K. Habel, **Performance and transmission properties of regional and long-haul WDM ring networks**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: Dr. Bachus.

M. Heidenreich, **2D Beschreibung von 3D Objekten (2D-description of 3D-objects)**, Hochschule für Technik und Wirtschaft Dresden, Fachbereich Informatik/Mathematik. Supervisor at HHI: K. Müller.

S. Kalyoncu, **Modellierung eines echtzeitrelevanten Steuerungskonzeptes für komplexen ASIC zur Video-Formatkonvertierung (Modelling of a real time control mechanism for a complex ASIC for video format conversion)**, TU Berlin, FB 13 (Informatik). Supervisor at HHI: T. Weber, K. Rümmler.

D. Karadoulamas, **Modellierung und Implementierung eines räumlichen Kanalmodells für den zellularen Mobilfunk (Modelling and implementation of a spatially resolved channel model for cellular wireless systems)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: H. Boche.

M. Krahn, **Entwurf und Entwicklung eines Linux-Treibers für eine High Level MPEG-2 Decoderkarte mit PCI-Schnittstelle sowie einer verteilten Applikationssoftware zum Funktionstest des Treibers (Design and development of a LINUX driver for a High Level MPEG-2 decoder card including a PCI interface and of an application software for functional checking)**, Fachhochschule für Technik und Wirtschaft (FHTW) Berlin. Supervisor at HHI: U. Höfker.

O. Krips, **Konstruktion einer Justiereinrichtung zur Ausrichtung von Lichtwellenleitern in einem Gerät zur Chip-Faser-Kopplung, (Construction of an adjusting device for adjustment of fiber-optic cables in a device for chip fiber coupling)**, Technische Fachhochschule (TFH) Berlin. Supervisor at HHI: U. Fischer.

S. Lange, **6-D Automatisierung der Faserarray-Chip-Kopplung (6D automation of fiber chip coupling)**, Fachhochschule für Technik und Wirtschaft (FHTW) Berlin. Supervisor at HHI: Th. Rosin.

A. Lerch, **Qualitätsbeurteilung von codierten Audiosignalen mittels eines objektiven Verfahrens (Quality assessment of coded audio signals by means of an objective procedure)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: M. Talmi.

Y. Li, **Ähnlichkeitsanalyse von 2D-Ansichten und 3D-Objekten in Szenen (Similarity analysis of 2D-views and 3D-objects in scenes)**, TU-Berlin, Fakultät IV (Elektrotechnik und Informatik). Supervisor at HHI: K. Müller.

Ch. Schmidt, **Analyses and Modelling of integrated optical Mach-Zehnder interferometer**, TU Berlin, Fakultät IV (Elektrotechnik und Informatik). Supervisor at HHI: M. Schlak.

A. Schweinzer, **Charakterisierung planarer thermo-optischer Schalter auf Polymerbasis (Characterization of polymer based planar thermo optic switches)**, Fachhochschule Nürnberg, FB Nachrichten- und Feinwerktechnik. Supervisor at HHI: C. Zawadzki.

Y. Song, **Untersuchung von Verfahren zur feingranularen qualitätsskalierbaren Videocodierung (Investigation of fine granular scalable video coding methods)**, TU Berlin, Lehrstuhl für Fernmeldetechnik. Supervisor at HHI: D. Marpe.

J. Tembridis, **Modellierung einer Testumgebung eines komplexen ASIC zur Formatkonvertierung (Modelling of a test environment of a complex ASIC for format conversion)**, TU Berlin, FB 13 (Informatik). Supervisor at HHI: T. Weber.

J. Wilhelmy, **Festkommaimplementierung eines psychoakustischen Modells auf dem**

Signalprozessor TMS 320C6211 für die Audiocodierung nach AAC-Standard (Fixed point implementation of a psycho acoustic model on the signal processor TMS 320C6211 for audio coding according to AAC standard), TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: M. Talmi.

G. Zander, **Untersuchung von Verfahren zur Wavelet-basierten Rauschunterdrückung in der Bilddatenverarbeitung (Investigation of wavelet-based denoising methods for image processing)**, Technische Fachhochschule (TFH) Berlin. Supervisor at HHI: D. Marpe.

S. Zech, **3D-Automatisierung der Faser-Chip-Kopplung (3D-automation of fiber chip coupling)**, Fachhochschule für Technik und Wirtschaft (FHTW) Berlin. Supervisor at HHI: U. Fischer.

GRADUATE THESES

S. Brahma, **Broadening the free spectral range of double-ring resonators including two different radii by resonance tuning**, TU Berlin, FB 12, Fachgebiet Hochfrequenztechnik. Supervisors at HHI: H. Heidrich, D. Rabus.

Y. Effendie, **Portierung eines AAC (Advanced Audio Coding) Decoders auf den digitalen Signalprozessor TMS320C6701 (Implementation of an AAC (Advanced Audio Coding) decoder on digital signal processor TMS320C6701)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: M. Talmi.

X. Fan, **Morphologische Nachverarbeitung von Segmentierungsergebnissen unter Echtzeitbedingungen (Morphological post processing of segmentation results under real-time constraints)**, TU Berlin, FB 12 (Elektrotechnik), Supervisor at HHI: R. Tanger.

J. Hurtienne, **mUltimo3D – Psychological studies on the design and evaluation of a multimodal computer system**, HU Berlin (Institut für Psychologie). Supervisor at HHI: S. Pastoor.

D. Kossack, **Modellierung und Implementierung eines CDMA basierten zellularen Mobilfunksystems (Modelling and implementation of a CDMA based cellular mobile communication system)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: H. Boche.

W. T. Marc, **Anwendungen des Mehrträgerverfahrens OFDM (The applications of OFDM)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: H. Boche.

Z. Zhu, **Tracking of the eyes in a video sequence under changing illumination**, TU Berlin (Institut für Elektronik und Lichttechnik). Supervisor at HHI: J. Liu.

ORAL PRESENTATIONS

T. Sikora, **Entwicklungstendenzen objekt- und modellbasierter Videocodierung** (invited lecture), Media Seminar of Technische Universität Ilmenau, 30.1.2001.

R. Steingrüber, **Elektronenstrahllithographie-Methode und Anwendung** (invited), Universität der Bundeswehr München, 30.1.2001.

M. Rohde, **DPSK as an alternative modulation format for WDM networks**, Workshop ITG-Fachgruppe 5.3.1, Darmstadt, January 2001.

R. Schäfer, **Verteilte Postproduktion in Gbit-Netzen: Konzepte, Implementierungen, Erfahrungen**, DFN Betriebstagung, Berlin, 6.-7.2.2001.

W. Passenberg, **Investigation of MBE growth parameters on the optical quality of GaInNAs quantum wells**, poster, Cost 2001, Würzburg, 27.2. 2001.

C. Caspar, **Dispersion management in high speed transmission systems**, Workshop T-Nova, HHI, VPI, COM, Lyngby (DK), February 2001.

M. Rohde, **Control modulation technique for the performance monitoring of WDM-Channels**, Workshop T-Nova, HHI, VPI, COM, Lyngby (DK), February 2001.

M. Rohde, **10 Gb/s DPSK transmission in WDM-Links**, Workshop T-Nova, HHI, VPI, COM, Lyngby (DK), February 2001.

C. Baack, **Das Breitband-Internet der Zukunft**, Vortrag beim ETV (anlässlich der Mit-

gliederversammlung des ETV), VDE Berlin, 17.3.2001.

H.-P. Nolting, M. Gravert, **Modeling of ultra fast optical clock based on tandem laser**, Workshop on Simulation of Optical Systems, OFC 2001, Anaheim (CA, USA), 19.-22.3.2001.

H. Künzel, C. Janke, P. Haring Bolivar, A. Bartls, H. Kurz, **Increased THz emitter efficiency by coherent superposition in a high repetition rate resonator**, Frühjahrstagung der DPG, Hamburg, 26.-30.3.2001.

M. Hahn, C. Huck, **Digitale Projektoren**, 5. Potsdamer Filmkolleg, Potsdam, 30.3.2001.

H.-P. Nolting, **All-optical 3R signal regeneration**, invited talk at Rank Prize Fund Workshop on "Terabit Networks", Windmere (UK), 4.4.2001.

M. Haardt, H. Boche, G. Wunder, **The future of mobile communications beyond the third generation**, 30. Annual IEEE Comm.-Theory Workshop, San Diego, April 2001.

P. Kauff, C. Fehn, E. Cooke and O. Schreer, **Advanced incomplete 3D representation of video objects using trilinear warping for novel view synthesis**, PCS '01, Seoul, Korea, April 2001.

D. Marpe, **ITU-T H.26L, current status of development of the generic next-generation video coding standard**, Fachbereich Informatik, Universität Rostock, 15.5.2001.

R. Schäfer, **Bildkompression für die Videoübertragung in Mobilfunknetzen** (invited), Kolloquium Digitale Mobilkommunikation, TU Berlin, 16.5.2001.

T. Sikora, **Next generation user interfaces** (invited plenary talk), Workshop Image Analysis for Multimedia Interactive Services, WIAMIS, Tampere (SF), 16.5.2001.

R. Schäfer, **Visuelle Maskierung und Kunstkopf – Meilensteine der Bildcodierung** (invited), IRT-Festkolloquium zum 60. Geburtstag von Dr. H. Wilkens, München, 30.5.2001.

H. Boche, **Multi-user receiver for CDMA-systems**, Elektrotechnisches Kolloquium der TH Karlsruhe, May 2001.

K. Müller, **Der MPEG-7-Standard: Inhaltsbeschreibung multimedialer Daten** (invited), 1. Thüringer Medianseminar der FKTG, May 2001.

C. Fehn, E. Cooke, O. Schreer and P. Kauff, **3D analysis and image-based rendering for immersive TV applications**, ICAV 3D '01, Mykonos (GR), May-June, 2001.

J. Bischoff, R. Brunner, S. Gliech, A. Duparre, J. Bauer, M. Ferstl, **Charakterisierung von lateralen Nanometerstrukturen mit optischen und nichtoptischen Messverfahren**, Jahrestagung der Deutschen Gesellschaft für angewandte Optik, (DGaO), Göttingen, 6.-9.6.2001.

H. Heidrich, **Monolithically integrated photonic and optoelectronic circuits based on InP – technology, system applications, perspectives –** (invited), Workshop Optical MEMS and Integrated Optics, Dortmund, 11.-12.6.2001.

T. Tekin, H. Ehlers, M. Schlak, J. Berger, C. Schubert, B. Maul, R. Ziegler, **All-optical demultiplexing performance of monolithically integrated GS-MZI module**, 1. Int. Workshop on Optical MEMS and Integrated Optics, Universität Dortmund, 11.-12.6.2001.

R. Schäfer, **Immersive media**, BMBF-Workshop, Internet und Medien – Anforderungen für die zukünftige Entwicklung in der Internet-Technologie, Bonn, 13.6.2001.

S. Bauer, **Laser based 3R regeneration for high-speed all-optical networks**, WAON2001, Zagreb (Croatia), 14.6.2001.

V. Jungnickel, **Breitbandige MIMO-Funkübertragung**, TU Dresden, Institut für Nachrichtentechnik, 18.6.2001.

R. Schäfer, **Immersive media for communication and infotainment**, DLR-Workshop, Successful Technology Transfer, Berlin, 21.6.2001.

A. Smolic, **Globale Bewegungsmodelle und Video-Mosaiken und deren Anwendungen in der Videoverarbeitung**, ITG-Fachgruppentreffen 3.1.2, Digitale Bildcodierung RWTH-Aachen, 22.6.2001.

G. Walf, **Impact of Optical technologies on future networks** (invited), Optical Networks

der EUROFORUM Deutschland GmbH; Freising, 27.-28.6.2001.

H.-G. Bach, **OEIC-Entwicklung für 40 Gbit/s Photoempfänger bis hin zur Modultechnik** (invited), Infineon Fiber Optics, Seminarreihe "Fiber Optics Produkte", Berlin, 13.7.2001.

N. Keil, **Komponenten der optischen Nachrichtentechnik mit Polymeren** (invited), Instituts-Kolloquium FhG IZM, Berlin, 17.7.2001.

V. Jungnickel, A. Forck, T. Haustein, U. Krüger, V. Pohl, C. v. Helmolt, **Wireless infrared communications beyond 100 Mbit/s: system design, transmission experiments and potential**, (invited paper), 5th World Multiconference on Systemics, Cybernetics and Informatics (SCI), Orlando (FL, USA), 22.-25.7.2001.

H. Boche, **Multi-user downlink beamforming**, Elektrotechnisches Kolloquium der RWTH Aachen, July 2001.

H. H. Yao, **Polymer waveguide devices for photonic networks**, Sorrento Networks Inc., San Diego (USA), 3.8.2001.

H. H. Yao, **Polymer waveguide devices: design and simulation** (invited), Seminar University of California, Los Angeles (USA), 6.8.2001.

H. H. Yao, **Research and development of polymer waveguide devices at HHI** (invited), Seminar Photon-X Inc., Malvern (USA), 8.8.2001.

R. Schäfer, **3D-Fernsehen und 3D-Dienste – die Technologie ist reif**, IFA 2001, Talk im TWF – Zukunft in 3D, Berlin, 29.8.2001.

C. Baack, **Internetzugangsnetze mit hoher Bandbreite und geringer Elektrosmogbelastung**, Workshop (Stand und Trends der Kommunikationstechnik) im Berliner Verbindungsbüro der Infineon Technologies AG, 13.9.2001.

H.-P. Nolting, **Devices for ultra-high speed all optical signal processing**, Workshop DYNAMICS OF SEMICONDUCTOR LASERS (Modeling, Analysis, Experiments), organized by WIAS, HHI, HU, Berlin, 13.-15.9.2001.

W. Passenberg, **GaInNAs/GaAs quantum well structures investigated by transient capacitance spectroscopy, photoreflectance and photoconductivity**, COST 268 MC/WG Fall Meeting, Lecce (I), 16.-19.9.2001.

H. Künzel, J. Böttcher, C. Möller, **MBE Wachstum bei reduzierter Wachstumstemperatur für optimierte GaAs Tunnelübergänge**, Nationaler MBE Workshop, Zeuthen, 17.-18.9.2001.

G. Walf, **Trends of optical Networks** (invited), Optical Internetworking der Marcus Evans Conferences, Berlin, 17.-19.9.2001.

C. Baack, **Spitzenforschung in Berlin**, Eröffnungsveranstaltung von u^{2}t Innovative Optoelectronic Components GmbH, Berlin, 24.9.2001.

C. Fehn, P. Kauff, O. Schreer and R. Schaefer, **Interactive virtual view video for immersive TV applications**, IBC '01, Amsterdam (NL), September 2001.

C. Fehn, P. Kauff and R. Schaefer, **Interactive Virtual View Video – Eine Erweiterung des immersiven Fernsehens**, DFS '01, Dortmund, September 2001.

T. Sikora and T. Meiers, **Hierarchical image search engines based on MPEG-7 descriptors** (invited lecture), Intern. Conf. On Image Processing, ICIP, Thessaloniki (GR), 10.10.2001.

H. R. Schäfer, **Image analysis and metadata extraction: Prerequisites for efficient image representation and coding**, VLBV 2001, Athen (GR), 11.-12.10.2001.

J. Faber, D. Ruschin, **Subjektive Bildqualität – eine Begriffsbestimmung zur Untersuchung von analoger und digitaler Kameratechnik im visuellen Vergleich** (invited), ARRI-Technologieforum, München, 19.10.2001.

J. Saniter, **TransiNet: Network elements and knode architectures in future optical networks**, Workshop on "How many dynamic will be needed in future transport networks?", HHI Berlin, 23.10.2001.

H. Boche, G. Wunder, **Channel estimation for MIMO-OFDM**, 39th Annual Allerton Conf. on Communication, Control and Computing, Urbana (IL, USA), October 2001.

S. Bauer, **Phasenkontrollierte 2-Moden-Pulsationen: Theorie und Experiment**, DFG-Kolloquium, Darmstadt, 5.11.2001.

W. Schlaak, **Phontonische ICs und Netze** (invited), Kolloquium des VDE, (Düsseldorf, Germany), 6.11.2001.

T. Tekin, **160 Gbit/s demultiplexer', seminar in optical fibre communication**, High Frequency Division (Photonics), TU Berlin, 16.11.2001.

G. Walf, N**ew evolutions of optical networks** (invited), DFN-Symposium des DFN-Vereins, Berlin, Germany, 19.-20.11.2001.

T. Sikora, **MPEG-7 content description interface – eine Übersicht** (invited lecture), Electrical Engineering Seminar of Universität Rostock, 23.11.2001.

U. Busolt, T. Tekin, C. Schubert, J. Berger, M. Schlak, B. Maul, W. Brinker, R. Molt, Ch. Schmidt, H. Ehlers, **Ultrafast all-optical signal processing by a monolithically integrated Mach-Zehnder-Interferometer**, Int. Workshop on Optical Signal Processing, Copenhagen (DK), 29.-30.11.2001.

H. Boche, **Optimale Algorithmen für das Joint Multiuse Downlink Beamforming**, Kolloquium über Elektronik und Nachrichtentechnik der ETH Zürich, November 2001.
H. Boche, **Optimal SIR balancing with multi-user downlink beamforming**, Prof. Paulraj, Stanford University, November 2001.

H. Boche, G. Wunder, **Peak to average power ratio for OFDM – new results**, Elektrotechnisches Kolloquium der ETH Zürich, November 2001.

M. Rohde, **Control modulation techniques for performance monitoring in transparent optical networks**, DFG Workshop, Darmstadt, November 2001.

E. Schulze, R. Freund, M. Malach, F. Raub, **8 x 10 Gb/s NRZ transmission over 1826 km and 10 Gb/s over 4000 km with distributed high-gain Raman amplification**, DFG-Colloquium, Darmstadt, November 2001.

R. Schäfer, **Immersive tele-conferencing – a key application for the next generation Internet** (invited), IST Conference 2001, Düsseldorf, 3.-5.12.2001.

K. Biermann, H. Künzel, D. Nickel, K. Reimann, M. Woerner, T. Elsaesser, **Ultraschnelle optische Nichtlinearität von LT GaInAs/AlInAs Quantentöpfen bei 1.55 µm**, DGKK-Workshop "Epitaxie von III/V-Halbleitern", Berlin, 6.-7.12.2001.

W. Passenberg, S. Mikhrin, H. Künzel, **MBE Wachstum und Materialeigenschaften von GaInAsN und GaAsN**, DGKK-Workshop "Epitaxie von III/V-Halbleitern", Berlin, 6.-7.12.2001.

F. W. Reier, **Optimierung von MOVPE-AlGaInAs/InP SL-MQW-Schichten für 1,3 µm-Laser**, DGKK-Workshop "Epitaxie von III/V-Halbleitern", Berlin, 6.-7.12.2001.

P. Wolfram, E. Steimetz, W. Ebert, B. Henninger, M. Rakel, J.-T. Zettler, **Optische in-situ Messungen an InP-basierenden Halbleiter-Strukturen**, DGKK-Workshop "Epitaxie von III/V-Halbleitern", Berlin, 6.-7.12.2001.

H. H. Yao, **Polymer components for DWDM networks** (invited Seminar) Shanghai Jiao-Tong University (China), 17.12.2001.

H. H. Yao, **Polymer waveguide devices for photonic network applications** (invited Seminar), Shanghai Jiao-Tong University, (China), 20.12.2001.

LECTURES

H. Boche, Digitale Mobilkommunikation I, TU Berlin

H. Boche, Digitale Mobilkommunikation II, TU Berlin

H. Boche, Mehrnutzerempfänger in der Mobilkommunikation, TU Berlin

H. Boche, Space-Time-Signalprocessing für die Mobilkommunikation, TU Berlin

H. Boche, Mehrnutzer-Informationstheorie, TU Berlin

H. Boche, TU-Kolloquium "Digitale Mobilkommunikation" jointly with Prof. P. Noll and Prof. A. Wolisz, TU Berlin

H.-G. Bach, Grundlagen der Halbleiterbauelemente, TU Berlin

H. G. Bach, Messverfahren für Halbleiterbauelemente, TU Berlin

E.-J. Bachus, Photonische Kommunikationsnetze, TU Berlin

L. Ihlenburg, Entwicklungstendenzen der Multimediakommunikation, TU Berlin

A. Kortke, H. Boche, Praktikum Space-Time-Signalprocessing, TU Berlin

B. Kuhlow, Einführung in die Photonik, TU Berlin

A. Paraskevopoulos, Halbleitertechnologie für die Integration in der Optoelektronik, TU Berlin

M. Rohde, "Optische Netze", as part of "Optische Nachrichtentechnik" by U. Fischer, TFH Berlin

O. Schreer, Multi-View-Geometrie in 3D Vision, TU Berlin

H. G. Weber, Grundlagen und Anwendungen der linearen und nichtlinearen Faseroptik, TU Berlin

G. Wunder, H. Boche, Statistische Signalverarbeitung, Detection and Estimation Theory, TU Berlin

WORKSHOPS ORGANISED

Workshop on Switching and Routing in Advanced Photonic Networks, organised by the IST OPTIMIST project in conjunction with ONDM 2001, Vienna University of Technology, February

ITG-Workshop Optische Aufbau- und Verbindungstechnik, HHI Berlin, May

Dynamics of Semiconductor Lasers, (in cooperation with WIAS, HU, FBH), Berlin, September

Annual review of national R&D programmes KomNet and OptoSys, HHI Berlin, September

Workshop on How many dynamic will be needed in future transport networks?, HHI Berlin, October

Press conference on the occasion of the annual review of R&D programmes KomNet and OptoSys, HHI Berlin, November

16. Workshop des DGKK-Arbeitskreises "Epitaxie von III/V-Halbleitern", Ludwig Erhard Haus, Berlin, December

CONTRIBUTIONS TO EXHIBITIONS

OFC 2001, Anaheim (CA, USA), March:
Demonstration of 40 GHz all-optical clock recovery
The German R&D Initiative KomNet

CeBit 2001, Hanover, February/March:
Mixed Reality: Interaction with virtual objects
BINDI – A busy indicator for telework and telecooperation

ECIO 2001, Paderborn, April:
Optical high speed components

Industrie-Messe-Hannover 2001, April:
Usability engineering at HHI

IFA 2001, Berlin, August/September:
3D PC – Towards novel forms of human-computer-interaction
KICK – Communication management in the Internet
Interactive streaming MPEG-4 player
Navigation in 360° Panoramen
Immersive TV- a new broadcast service
Stereo television demonstrator system (3D-TV)
PC- and DSP-based AAC codec
PC-, DSP- and RISC-processor-based audio/video decoder
Broadband mobile communication

IBC 2001, Amsterdam (NL), September:
PC- and DSP-based AAC codec

Poster Exhibition, Berlin, September:
The national R & D programmes KomNet and OptoSys

ECOC 2001, Amsterdam (NL), September/October:
KomNet – German R & D initiative on optical transport and networking technologies for the emerging broadband Internet
Demonstration of an all-polymer athermal arrayed waveguide grating multi-/demultiplexer

MMC Workshop, Berlin, HHI, November:
Interactive Streaming MPEG-4 Player
Effiziente Repräsentation und Darstellung hochaufgelöster 360°-Panoramen

Poster Exhibition, Berlin, November:
KomNet – On the way to the next generation Internet

Elektronische Automatisierung, Nürnberg, November:
CabrioScreen (autostereoscopic 3D display with infrared head tracker, jointly with ACT Kern)

IST Event 2001, Düsseldorf, December:
Demonstration of the next generation video-conferencing system by the IST project VIRTUE

WDR Computerclub: Lange Nacht der Computer III, Köln, December: Interactive streaming MPEG-4 player

COMMITTEE ACTIVITIES

Standardisation Committees

DVB Technical Module: Member
ISO/MPEG

ITU-T, SG 16, Associated Rapporteur

Research Program Committees

COST 211: Member

COST 266, Progress of Photonic Infrastructure towards the IT-Age: Member

COST 267, Semiconductor devices for signal processing WG2: Chairman

COST 268, Management Committee: Member (deputy)

DFG Keyprogram "Optical Signalprocessing": Evaluator

IST (Inform. Society Technologies): Evaluator
Strategische Plattform Informationstechnik: Member

Technology Foundation STW: Evaluator

Conference and Workshop Program Committees

Consultations Meeting PCM Program Committee: Member

DGKK Workshop: Epitaxie von III-IV-Halbleitern: Chairman

9th Dortmunder Fernsehseminar: Program Committee

ECOC Technical Program Committee: Member

10th European Conference on Integrated Optics (ECIO '01), 2001, Paderborn, Germany: Program Committee Member

Human Factors in Telecommunications: Permanent Steering Committee

Integrated Photonic Research 2001, Monterey, CA, USA

10th Intern. Plastic Optical Fibres Conf. (POF 2001): Program Committee Member

14th International Conference on InP & Related Compounds (IPRM '02), Stockholm: Program Chair

International Picture Coding Symposium: Steering and Program Committee Member

International Zurich Seminar (IZS 2002): Program Committee

Media Futures Conference: Program Committee

Münchner Kreis, Congress "eCompanies founding, growing, harvesting": Program Committee Member

Nonlinear Guided Waves and their Applications Topical Meeting, Cost 211: Member

Packet Video Workshop: Program Committee

SPIE Design, Manufacturing and Testing of Planar Optical Waveguide Devices: Program Committee Member

Technisch-Wissenschaftliches Forum IFA '01
Very Low Bitrate Video Workshop: Program Committee

Editorial Boards

EURASIP Signal Processing

IEEE Signal Processing Magazine: Associate Editor

IEEE Transactions on Circuits and Systems for Video Technology: Editor-In-Chief

Image Communication: Associate Editor

Image Communication: Guest Editor

Institute of Physics (GB)/Semiconductor Science and Technology: Referee

Springer Verlag Berlin, Heidelberg, Series "Photonics": Co-Editor

Advisory Boards

Photonic Network Communications

Other Committees

Arbeitskreis Integrierte Optik (AKIO): Member

Aspen Institut Berlin: Member

Competence Center for the Application of Nanostructures in Optoelectronics (NanOp): Member of Executive Board

FKTG, Urtel-Preis-Komitee: Curatorship

ITG, FA 3.1 Fernsehtechnik und elektronische Medien: Chairman

ITG, FG 3.1.2 Digitale Bildcodierung: Chairman

ITG FG 5.2.5 Access- und Inhouse-Netze: Member

ITG, FA 5.3 Optische Nachrichtentechnik: Member

ITG, FG 5.3.1 Modellierung photonischer Komponenten und Systeme: Committee Member

ITG, FG 5.3.2 Photonische Integrations- und Aufbautechnik: Chairman

ITG, FG 5.3.3 Photonische Netze: Member

ITG, FG 5.4.1 Optische Polymerfasern: Member

LMTB - Laser und Medizin-Technologie gGmbH, Berlin: Advisory Committee

Münchner Kreis, Supranational Association for Communications Research: Research Committee

OPTEC BB, Berlin: Member

TSB-Technologiestiftung Innovationszentrum Berlin: Board of Curators

TWF (Technisch-wissenschaftliches Forum) IFA '01

VDI optische Technologien: Advisory Board

EXCHANGE PROGRAM

Scientists Visiting HHI

K. Biermann, Max-Born Institut, Berlin, financed by Max-Born Institut, for four years

H. Bölcskei, University of Illinois at Urbana-Champaign (USA), financed by by University of Illinois and HHI, for one month

R. Freund, Fa. VPI, Berlin, financed by VPI, for two years

F. Futami, Fujitsu Laboratories Ltd., Nakahara-ku, Kawasaki (J), financed by Fujitsu, for one month

M. Gionannini, Institute Politecnico di Torino (I), financed by COST 267, for two weeks

V. Haisler, Institute of Semiconductors, Novosibirsk (RUS), financed by TU Berlin, for ten months

K. Iiyama, Kanazawa University (J), financed by Kanazawa Univ., for eight months

I. Koichi, Kanazawa University (J), financed by Kanazawa University, for eight months

V. Kravcenko, TU Berlin, financed by TU Berlin, for one year

V. Mamutin, Abraham Ioffe Institute, St.

Petersburg (RUS), financed by HHI, for one year

S. Mikhrine, Abraham Ioffe Institute, St. Petersburg (RUS), financed by HHI, for seven months

C. Plakas, Heriot-Watt-University, Edinburgh (UK), financed by Heriot-Watt-University, for three weeks

G. Reißig, Massachussetts Institute of Technology (MIT), financed by MIT and HHI, for 2 weeks

N. Sabelfeld, MergeOptics GmbH, Berlin, financed by MergeOptics GmbH, for one year

S. Watanabe, Fujitsu Laboratories Ltd., Nakahara-ku, Kawasaki (J), financed by Fujitsu, for one month

T. Yamamoto, Fujitsu Laboratories Ltd., Wakamiya (J), financed by Fujitsu, for one year

HHI Scientists Visiting Foreign Institutes

U. Kowalik, Tokyo University, Tokyo (J), financed by HHI, for one year

B. Rathke, TU Berlin, financed by HHI, for one year

COOPERATIONS

Industry

Acterna, Eningen

A.C.T. Kern, Donaueschingen

Agilent Technology, Ipswich (GB)

Aifotec GmbH, München, Berlin

Aixtron, Aachen

Alcatel SEL, Stuttgart

Alcatel, Paris

ASM Lithography, Veldhoven (NL)

ATIP GmbH, Frankfurt/M.

Atomika Instruments GmbH, München

AXON Photonics, Livermore (USA)

Bayerischer Rundfunk, München

BBC, London

Bertelsmann, Gütersloh

Bioshape AG, Berlin

Blaupunkt-Werke GmbH, Hildesheim

British Telecom, Martelsham Heath, Corning (GB)

Canto, Berlin

Carl Zeiss, Jena, Oberkochen

com center, Kopenhagen (DK)

Cybertron, Berlin

DaimlerChrysler, Ulm

das werk, München

Deutsche Bank, Berlin

Dr. Detlef Rose Fotomasken Mikroelektronik, Bergisch Gladbach

D-Research Digital Media Systems GmbH, Berlin

DSPecialist, Berlin

EPIGAP Optoelektronik GmbH, Berlin

Ericsson Eurolab, Aachen

Fresnel Optics GmbH, Apolda

Fujitsu Laboratories Ltd., Wakamiya (J), London (UK)

Fujitsu Mikroelektronik GmbH, Dreieich-Buchschlag

Hitachi Central Research Laboratory, Tokyo, Cambridge (UK)

HoloEye GmbH, Berlin

Infineon Technologies, Berlin, Regensburg, München

INM – Institut für neue Medien, Frankfurt/M

Ionas, Lyngby (DK)

ISIS Optronics, Mannheim

JDS Uniphase, Eindhoven (NL)

Kerpenwerke, Stolberg

Knowbotic Systems, Frankfurt/M

Laser Components GmbH, Olching

Laytec GmbH, Berlin

Loewe-Opta GmbH, Kronach

Lucent Technologies, Nürnberg, Holmdel (USA)

Lynx Photonic Networks (USA and IL)
Medav Digitale Signalverarbeitung GmbH, Uttenreuth

MergeOptics, Berlin

Mikrom, Berlin

moove, Leverkusen

Nawotec GmbH, Rossdorf

neomagic (IL)

NTT Advanced Technology Corporation, Tokyo

Nokia, Espoo (SF)

Optibase, Herzliya (IL)

Opto+, Paris

OptoSpeed SA, Darmstadt, Zürich

Optovation Inc., Kanata (CDN)

Philips BV, Eindhoven (NL)

Quantum Devices Inc. (QDI), Yorba Linda, CA (USA), Berlin

Robert Bosch GmbH, Hildesheim, Stuttgart

SCHOTT GLAS, Mainz

Siemens AG, Berlin, München, Regensburg

Sony UK, Sony Stuttgart

Tecsi, Paris

Telenor, Oslo

Teracom AB, Stockholm

Tesat-Spacecom GmbH & Co. KG, Backnang

Thomson CSF Optonique, Paris

TOPTICA Photonics AG, München

T-Systems Nova, Berlin, Darmstadt

Tyco Electronics GmbH, Berlin

u^2t Innovative Optoelectronic Components GmbH, Berlin

Vcon Telecommunications Ltd. (IL)

Virtual Photonics Inc., Berlin, Melbourne, Freehold (USA)

vision pearls, Berlin

Vodafone Ltd., Newbury (GB)

2SK Media Technologies, Berlin

Universities and Institutes

Brunel University, Uxbridge (GB)

Central Electronic Engineering Research Institute, Pilani, Indien

Denmark Technical University, Kopenhagen

DFN-Verein, Berlin

DLR Stuttgart

ETH Zürich

ETRI, Taejon (Korea)

European Broadcasting Union, Genf

Fachhochschule für Wirtschaft und Technik (FHTW) Berlin

Ferdinand-Braun-Institut, Berlin

FhG Institut für Biomedizinische Technik

FhG Institut für Integrierte Schaltungen, Erlangen

FhG Institut für Medienkommunikation (FhG-FOKUS), Berlin

FhG Institut für Mikroelektronische Schaltungen und Systeme, Duisburg

FhG Institut für Zuverlässigkeit und Mikrointegration, Berlin und Teltow

FhG / IGD, Darmstadt

FhG IOF Jena

FhG Institut Siliziumtechnologie, Itzehoe

Forschungszentrum Kossendorf

Freie Universität Berlin, Fachbereich Physik Hahn-Meitner-Institut, Berlin

Heriot-Watt University, Edinburgh (GB)

Hochschule Harz, Wernigerode

Humboldt-Universität zu Berlin

IAF Freiburg

INRIA, Paris

Institut für Physikalische Hochtechnologie – IPHT, Jena

Institut für Rundfunktechnik, München

Ioffe-Institut, St. Petersburg (RUS)

IRISA, Rennes (F)

Konrad-Zuse-Institut, Berlin

Max-Born-Institut, Berlin

MPI Halle

Paul-Drude-Institut, Berlin

Poznan University of Technology (PL)

Queen Mary Westminster College, London

Senatsverwaltung für Finanzen, Berlin

Senatsverwaltung für Wirtschaft u. Technologie, Berlin

Stanford University, CA (USA)

Technische Fachhochschule Berlin

Tohoku University, Sendai (J)

Tokyo University

TU Berlin

TU Braunschweig

TU Chemnitz/Zwickau

TU Darmstadt

TU Delft (NL)

TU Denmark, Lyngby

TU Dresden

TU Hamburg-Harburg

TU Ilmenau

TU München

TU Wien (A)

Universität Aachen

Universität Bremen

Universität Dortmund

Universität Erlangen-Nürnberg

Universität Jena

Universität Rostock

Universität Stuttgart

University of Torino (I)

Universität Würzburg

University of Illinois at Chicago (USA)

University of Linz (A)

University of North Carolina, Chappel Hill (USA)

University of South Carolina, Columbia, (USA)

University of Patras (GR)

University of Torun (PL)

Weierstraß-Institut für Angewandte Analysis und Stochastik (WIAS), Berlin

Zentral- und Landesbibliothek, Berlin

Technology Collaboration Networks

NanOp, Berlin

Optec BB, Berlin

START UP COMPANIES

DSPecialists GmbH, Berlin
DSPecialists develops systems and tools for digital signal processing using digital signal processors (DSP). Its focus is to provide platforms in software and hardware for customers in various branches, such as audio, video, telecom and measurement/control. DSPecialists sells its products and provides different kinds of services, such as technical training and application development.

Virtual Photonics Incorporated (VPI)
VPI Virtual Photonics makes design and planning tools for access providers, network operators, system integrators and manufacturers of WDM transmission systems and optical components. Lead customers include Alcatel, Hitachi, Deutsche Telekom, Lucent, Pirelli, MCI and Sprint. Siemens, Telcordia and Open Telecommunication are worldwide business partners.
VPI employs 150+ technical experts, consultants, developers and sales persons. Offices are located in Berlin, Munich (Broadband Access), Holmdel, NJ (IP/Optical Networking), Australia (Optical Systems) and Minsk (Software Production). Investors include Weiss, Peck & Greer, Siemens, Techno Venture Management and Deutsche Telekom.

2SK Media Technologies GbR, Berlin
2SK Media Technologies develops and markets software for compression and decompression of audio and video signals according to the MPEG standards. Its main product is the MPEG SoftEngine, which currently supports MPEG-1 and MPEG-2. Future products, which will support MPEG-4 and MPEG-7, are under development.

MikroM, Berlin
MikroM develops and designs VLSI components for image and sound processing and compression. Its main product is HiPEG+, a single chip HDTV decoder according to the Main Profile@High Level of MPEG-2. This chip, which is based on the HiPEG chip previously developed at HHI, contains the video decoder and the systems demultiplex.

u^2t Photonics AG, Berlin
u^2t Photonics AG was founded in 1998 by three scientists of HHI and is now recognized worldwide as a leading-edge supplier for the optical telecommunications market. U^2t develops and manufactures innovative optoelectronic components for the highest speed applications. Flagship is an ultrafast photodetector with more than 50 GHz bandwidth, capable of handling very high input power. Other products such as photoreceivers and modulators are especially designed for 40 Gbit/s communication systems.
In 2001, u^2t merged with another HHI spin-off, LKF Advanced Optics GmbH to combine their complemetary product portfolios. For more information please visit www.u2t.de or mail to contact@u2t.de.

Usability Lab am HHI, Berlin
The company supplies Human Factors and Usability support at all phases of the product life cycle. For all information and communication technology products (services, systems, terminals, user interfaces, etc.) it offers user requirements analyses (based on empirical studies), design studies with detailed recommendations, evaluation of prototypes and products already on the market (by means of Cognitive Walkthroughs, Heuristic Evaluation, and Usability tests with test subjects), and consultancy in terms of strategic decisions on product lines.
(www:http://ulab.hhi.de)

MicroShape, Berlin
MicroSHAPE (Software and Hardware Application Engineering) develops software and hardware components and tools focusing on digital image processing. Furthermore MicroSHAPE develops complete prototype systems and peripheral units. Starting at schematic architectures via structure simulations and layout designs up to high integrat-

ed FPGA developments, all steps are micro accurately done by this company. The first product will be a digital to analogue interface module for HDTV projection systems compliant to the DVB and ATSC standard.

Perspective Technologies GmbH (PT), Berlin

Perspective Technologies GmbH Berlin is a 3D display and interaction systems development and marketing company founded by a team of scientists of the HHI and experts in the fields of market research, business strategy and innovation management. Perspective Technologies is pioneering the combination of highest-quality 3D technologies with novel non-intrusive user-interaction systems. As a result, PT's displays produce stunning 3D effects without the need of any encumbering viewing aids, such as stereo glasses or head-mounted devices. The proprietary interaction technologies are based on the latest results in digital image processing and computer vision research. First 3D display products will apply the lenticular lens technology, adapted to range of target applications, e.g. in medical imaging, molecular design and 3D CAD.

HHI AT A GLANCE

Government research institute (Federal Republic of Germany and State of Berlin)
Total staff at end of 2001: 272 employees

Areas of Research and Development

Photonic Networks

- Design, development and demonstration of optical communication networks and subsystems (access and customer networks, core networks)
- Investigation and development of WDM and high-speed OTDM techniques for high capacity transmission and routing
- Exploration of high speed transmission performance of photonic networks
- Development of techniques for network operation and maintenance
- Development and fabrication of photonic devices and integrated circuits (lasers, modulators, switches, optical amplifiers, filters, multiplexers and demultiplexers, signal regenerators, transceivers, receiver frontends) based on InP, for passive components on SiO_2/Si and polymers
- Development of new concepts for carrying IP traffic over WDM optical networks and wireless networks in an efficient manner (TransiNet)
- Switchable network design and testing

Mobile Broadband Systems

- Development of space-time-receiver for the uplink of mobile communication systems
- Design of downlink beamforming for CDMA-based mobile communication systems
- Development of calibration algorithms for smart antennas
- Teletraffic engineering for mobile communication systems
- Development of signal processing algorithms for OFDM systems
- Development of sequences for CDMA applications
- Development of optical microwave generation and transmission systems for cellular mobile communication systems
- Implementation of MIMO systems
- Development of signal processing algorithms for MIMO systems

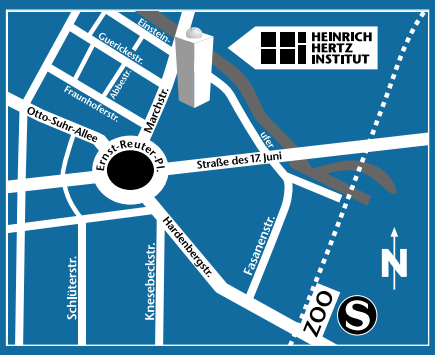
Electronic Imaging Technology for Multimedia

- Development of algorithms and hardware architectures for video and audio compression
- Development of algorithms and hardware architectures for image analysis and synthesis
- 3D signal processing for tele-immersion
- Image processing for studio applications
- Video-streaming over IP and mobile networks
- Design of integrated circuits for image processing
- Development of 3-D display technologies
- Man-machine-interaction for future 3D-desktop applications
- Virtual reality for telework and telecommunication
- Development of user interfaces for multimedia applications
- Analysis and optimization of communication services
- Image and video retrieval systems

HEINRICH-HERTZ-INSTITUT FÜR NACHRICHTENTECHNIK BERLIN GMBH

Einsteinufer 37, 10587 Berlin
Germany
Phone: +49 (0)30 3 10 02-0
Fax: +49 (0)30 3 10 02-213
Email: Contacts@hhi.de
http://www.hhi.de

Scientific Managing Director:
Prof. Dr. Clemens Baack
Administrative Managing Director:
Dr. Wolfgang Grunow



ISSN 1435-1587