HEINRICH-HERTZ-INSTITUT

REPORT 2002

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HHI REPORT 2002

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FUNDAMENTALS

During 2002 the Heinrich-Hertz-Institut für Nachrichtentechnik Berlin GmbH (HHI) was in a state of flux. On 30 April the two long serving managers, Professor Dr. Clemens Baack and Dr. Wolfgang Grunow, retired. They imbued the HHI with their competence to become an important research centre for telecommunications. On 12 July the shareholders changed too, when the Federal Republic of Germany and the State of Berlin transferred the Institute to the "Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.", München (Fraunhofer Society for the Promotion of Applied Research, Munich) (FhG). For the legal transfer to the FhG the HHI GmbH was first of all converted to the HHI für Nachrichtentechnik Berlin e.V. & Co. KG and then integrated into the FhG, with effect from 11 November 2002. Since then the HHI operates as the Fraunhofer-Institut für Nachrichtentechnik (Fraunhofer Institute for Telecommunications) with the additional trading name Heinrich-Hertz-Institut.

The transition is proceeding smoothly. To fulfil the most important criterion, namely the strengthening of the earning capacity of the HHI, there remains a leeway to about 2007. By then the HHI must increase its proportion of income from outside sources from about 60 % to 80 %.

A serious problem was and is the filling of the management position (now: Director of the Institute). The Fraunhofer Society and the Technical University Berlin (TUB) have agreed that the new Head of the Institute will be appointed as a C4 Professor of Telecommunications at the TUB and at the same time Director of the HHI. The procedure for this appointment means that the head of the new HHI Institute cannot take office till autumn 2003 at the earliest.

For the transitional period the new and old shareholders have, in agreement with the Board, engaged its former chairman, Professor Dr. Joachim Hesse, to manage the HHI from 1 May. Under his control the HHI is applying itself mainly to enhancing its earning capacity. In the foreground will be the relevance to industry of the three research areas. The HHI has in the mean time taken the following steps to increase its earning power:

- It has modified its management structure. All important procedures relevant to business will be prepared by a committee consisting of the heads of department and the executives of important service areas of the HHI;
- It has ensured transparency of the recommendations or decisions by the executive committee via minutes and with follow-up information to all staff;
- It has decided budgeting and costing (other income, establishment income) by balancing performance across departments;
- It has introduced an investment shareout to the departments based on their external income, after first deducting investment for maintenance and expansion of the service areas, as discussed by the executive committee;
- It has set up a department-oriented marketing system with central coordination;
- It has passed guidelines for its patent policy, for internal cooperation, for further training and for the development of leaders.

These guidelines have stimulated research in 2002. In that year the HHI had an authorised expenditure of € 33.1 million, but the actual expenditure was around € 30.7 million. The plan was that € 18.4 million of this should be covered by income from paid third party research projects, but because of a delay in approving all the projects, those that were approved could only bring in € 16 million in 2002. On the whole this is a remarkable result in view of the increasingly difficult market conditions. The table shows the individual sources of third party income, together with last year's figures for comparison:

Financial Overview	€ (millions)	
	2001	2002
Expenditure	29.5	30.7
Establishment income	14.0	14.7
Other income	15.5	18.4
Other income sources:		
• Industry	3.1	3.6
• General business	0.9	1.1
• EU	0.4	0.9
• BMBF/BMWi	9.1	10.4
• State of Berlin	0.1	1.7
• DFG	0.8	0.7
• Other	1.1	–

The industry component was quite good in terms of the old HHI GmbH guidelines, but the usual FhG standard is higher. There is a strategic deficit in the low EU quota. An attempt to increase this is required, if only because suitable R&D partners are the key for accessing European industry.

In 2002 the HHI has safeguarded its support for R&D activities with 19 patent applications (previous year: 22) and has documented its scientific results in 242 publications (previous year: 153). 22 lectures or seminars have been given by members of its staff at the cooperating universities, mainly at the TUB (previous year: 17). The HHI also employed on average 79 scientific assistants (previous year 80). 12 students have written their theses on HHI topics (previous year: 18). Also, 4 of its employees received a doctorate (previous year: 2).

At the end of 2002 the HHI had 274 employees (previous year: 272), of whom 155 were scientists (previous year: 153). The HHI has therefore maintained its personnel establishment. The FhG has made a binding promise to take over this level of personnel. An amount of € 6.6 million was invested (previous year: 6.8).

The HHI expresses its thanks to its previous shareholders, its Board and Science Council for a long period of good cooperation and active support.

The HHI starts its first year within the Fraunhofer Society with confidence.

Berlin, January 2003
Joachim Hesse

Mission, Activities, Personnel and Financing

Information technology provides the communication 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 evolution of communication networks has led to a huge, multi $100 billion market. Although we are currently witnessing a persevering market downturn and a sometimes dramatic worldwide readjustment of industrial capacities, the user demand for broadband services is still growing, and the roadmaps for research and development existing in this field have not undergone greater revisions apart from retarded forecasts for the introduction of the next technology generation.

The paramount task in information technology is the development of a seamless global network, which is structured into an optical Core Network, high capacity fibre optics 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, at a low price.

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 up to 320 Gb/s as well as measurement methods. 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. Today, "fibre to the home" has become a very active R&D area aiming at 100 to 1000 Mb/s subscriber lines, while customer in-house networks with a fibre optic infrastructure and wireless access require extremely cost-efficient solutions.

Our research and development work on photonic devices focuses on the next generation metro and core networks. Key components under development are uncooled semiconductor lasers for direct 10 GHz modulation and flip-chip mountable broadband photodiodes for transceivers to be used in the 10G Ethernet; lasers for WDM networks, including ring lasers and associated filter elements; picosecond pulse laser sources, fast electro-optical 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 274 employees, 155 of whom were scientific staff and 127 technical and administrative staff. Of these, 127 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 45 in central functions such as management, planning, administration and workshops. At the end of the year there were also four postgraduate doctoral students, eight persons in training, 79 student assistants and three guest scientists working at the HHI.

In 2002 the overall budget amounted to EUR 30.7 million. The external funding represented 59.9 % of the budget which included 15.3 % from direct contracts with industry. Cooperation agreements were concluded with the leading IT companies in Europe. HHI continues to be a member in the Alcatel Research Partnership Program, under which advanced research projects in all-optical signal processing, ultrahigh bit rate transmission, semiconductor materials technology, and optical polymer devices are being carried out. The joint national project KomNet (sponsored by BMBF and coordinated by HHI) was successfully concluded in April 2002. HHI has won several contracts in the successor project Multi-Teranet which started in September 2002 and is geared to the future generation of optical core and broadband metro/access networks and their key components.

HHI has increased its engagement 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. In May 2002 a joint R&D project sponsored by the Innovation Programme Berlin was launched to develop development key components for the 10G Ethernet with three Berlin based start-up-companies and HHI.

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 (International Conference on Optical Fiber Communication (OFC), European Conference on Optical Communication (ECOC), European Microwave Conference) and at prominent trade fairs (CeBIT, Hannover Messe, Laser Optics Berlin, etc.).

Last but not least, services in the areas of testing and measurements, feasibility studies, design work, e-beam mask plate manufacturing, epitaxy wafer and semiconductor processing services, 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 again recertified in November.

Corporate Bodies

The corporate bodies of the HHI are the General Meeting, the Supervisory Board, the Managing Directors and the Scientific-Technical Committee. Due to the changing of the shareholder of the institute, the activities of the corporate bodies and committees have been ended by November 2002.

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 B. D. Lietzau, (2nd vice-chair), Senatsverwaltung für Wissenschaft, Forschung und Kultur, Berlin
Prof. Dr. J. Eberspächer, Technische Universität München
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
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
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R & D Activities

R & D FIELDS

Photonic Networks

Topics and Results

The worldwide communication traffic continues to increase at a growth rate of about 100 % per year. 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 mainspring for commerce and business. The basis of this high capacity communication system will be optical fibre communication, which will utilize photonic networks in the core network and broadband fibre in-house networks at the customers' premises. Prognoses for access data rates are 150 Mbit/s for private customers and several gigabit per second for business customers. The enormous fibre capacity of more than 60 terahertz will be accessible using optical wavelength-division multiplexing (WDM) and optical time-division multiplexing (OTDM) techniques. In photonic networks the information is not only transmitted optically, but also routed in the optical domain.

The R&D activities of HHI comprise all aspects of photonic networks, from photonic component technology to the systems side; e.g. exploitation of the large fibre bandwidth, optical switching, network investigations, optical signal processing, and component developments. The projects are funded by the German government, the State of Berlin, the European Union, the information and communication industry and network operators.

During the last four years, one of the higher-ranking goals of the German research initiative KomNet, which finished in 2002, was to develop a set of system-level solutions for the future broadband Internet through 25 individual R&D projects, mainly lead by industrial partners, and to perform cross-project testing and demonstrations under real-life operating conditions. In particular the interworking of high-technology photonic systems developed by various manufacturers was tested and field-trialled using the existing standard single mode fibres, which are widely used throughout Europe.

HHI contributed to the KomNet program with several projects, as well as through subcontracts to industrial partners. These projects and subcontracts included 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 and receivers, all-polymer add-drop multiplexers, optical signal regenerators, transceiver photonic integrated circuits, and picosecond opto-electronic integrated circuits. In addition, the HHI Systems Integration Office was responsible for coordinating the experimental network construction and cross-project field trials. The large number of excellent results achieved provide a solid basis for solving current tasks of product-oriented development, and for further research on photonic communication networks, e.g. under the framework of the German Government's new funding priority called MultiTeraNet. This program addresses topics such as flexible optical networks, access networks, exploitation of the fibre capacity and key components and technologies.

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

- Photonic networks and systems
- Ultra-fast optical signal processing and transmission
- InP components and OEICs
- Photonic components based on polymers and SiO_2/Si

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 component projects, and improve the mutual 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 overall research area of photonic networks is focussed on the two areas Core and Metro Network and Access and Customer Network.

Core and Metro Network

Work in this research area concentrates on dense wavelength-division multiplexing (DWDM) and high bitrate time-division multiplexing (TDM) techniques, optical crossconnects, 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. 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 monomode 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 bitwise switching. The RZ data source is 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 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 realized 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 (λ_0 = 1547 nm).

All-optical signal regeneration: Scalable networks need full 3R (re-amplification, reshaping, 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 at frequencies of more than 80 GHz have now been achieved using the new PhaseCOMB 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.

A novel type of self-pulsating laser based on the "Amplified Mirror Concept" has been developed. First devices have been fabricated and characterized. This component has only one DFB section and one amplifier section. This simplifies the fabrication, which results in higher yield.

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

A new switching architecture based on an alternating data clock scheme (ADC) has been successfully used for 3R regeneration at 10 and 40 Gbit/s. This architecture has a number of advantages over commonly used circuits. With the use of ADC, any wavelength converter can be used as a decision element in a 3R regenerator. The speed limit of optical semiconductor amplifiers (SOAs) is increased significantly by this scheme. Specially important for DWDM systems is the free choice of the output wavelength of a CW laser. Applying this concept, the first

semiconductor-based all-optical 3R regenerator at 40 Gbit/s has been realized.

In cooperation with ALCATEL, an all optical 3R regenerator for 160 Gbit/s is under development. The key components are the PhaseCOMB laser for clock recovery and the Mach-Zehnder (MZ) SOA switch as the synchronous modulator.

A first step was taken towards a 160 Gbit/s 3R regenerator based on a hybrid electro-optic architecture. A 3R regenerative wavelength converter at 160 Gbit/s was demonstrated. It comprised four elements: a pulse shaper, a decision gate, an optical clock and a wavelength shifter. The decision gate was realized using cross-phase modulation in highly nonlinear fibre with the nonlinear coefficient $\gamma = 20\ W^{-1}\ km^{-1}$. An optical gate based on the same fibre was also operated in an optical sampling system for monitoring eye diagrams at data rates up to 320 Gbit/s. Finally, a new optical clock recovery unit for data rates up to 160 Gbit/s was developed based on electro-absorption modulators.

Monolithically integrated picosecond pulse source: One area of prime interest to HHI is the development of components and subsystems for OTDM/WDM systems with single fibre transmission capacity in the terabit per second range. Key components for 160 Gbit/s OTDM systems are pulse sources with 40 GHz repetition rates and less than 1.5 ps pulse widths, and a monolithically integrated mode-locked laser meeting these demands is currently under development. In particular, a 2.2 ps pulse width and a 500 MHz tuning range with less than 300 fs jitter have been demonstrated.

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. The reduction of the polarization sensitivity of these switches is a crucial task for application in a network. Less than 2 dB polarization sensitivity for the signal path have been demonstrated. Furthermore a reduction of the optical loss is necessary.

In a new project with ALCATEL, the speed of the MZ-SOA switch will be increased to use it as a synchronous modulator up to 160 GHz.

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 (more than 6 V), and as a consequence need 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 (less than 3 mm^2) and needs less driving voltage ($V_{pp} \approx 2V$) 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: The R & D project TWINPD, a part of the KomNet initiative, was completed in 2002. It resulted in the fabrication of several differential photodetector modules. The achievements included bandwidths exceeding 45 GHz, differential polarization-dependent losses as low as 0.15 dB, an output current asymmetry of only 0.2 dB, and better dynamic behaviour than with single photodiodes. These receiver modules were successfully applied in a field trial conducted by an industrial partner. Balanced photodetectors were also developed using the same integration scheme. When packaged into modules, they had well opened eye patterns at 40 Gbit/s.

The pinTWA photoreceiver, comprising a waveguide-integrated photodiode and a HEMT-based travelling wave amplifier, was improved by implementing a galvanic separation between the amplifier's ground and the RF output ground. This avoids the lossy and costly bias-T, which has hitherto been needed to operate the pinTWA photoreceivers. A bitrate conversion capability of 60 Gbit/s was demonstrated.

The development of even faster photoreceivers is continuing in the MultiTeraNet Program. Here the goals for broadband optoelectronic conversion rates are extended into the 80 to 160 Gbit/s data range. In particular, receivers operating at 80 Gbit/s are of immediate interest for our industrial partners, as they intend to carry out first system trials at this extended transmission speed in the near future. HHI's role within MultiTeraNet is to develop broadband pho-

toreceivers for this data range and to provide samples to its industrial partners within the next three years.

The activities with high-speed photodetectors and receivers are complemented by a project in which, in cooperation with the Fraunhofer Institute for Reliability and Microintegration, advanced packing technologies for frequencies of up to 100 GHz are being developed.

Design strategies to utilize the maximum transmission capacity of WDM systems: The goal of this novel topic is to develop upgrading strategies to exploit the maximum capacity of modern fibre systems. The strategy starts with the C band and continues to the whole optical bandwidth of single mode fibres, covering the wavelength region from 1300 nm to 1675 nm. This region provides a nominal information bandwidth of about 50 THz. The upgrading strategy should allow the addition of new optical bands without disturbing the already existing ones. This is of great practical interest for network providers operating different systems on different fibre infrastructures. As an example, the application of Raman amplification must be considered when upgrading the links. Mutual influence through nonlinear interactions is expected by implementing a plurality of Raman pump channels within combs of client information channels.

Another problem not yet well understood is polarization-mode dispersion at very high channel rates in conjunction with nonlinear effects. It is planned to investigate the transmission properties of WDM systems with an extremely large number of channels by simplified simulations and analytical methods. The theoretical results are to be verified in selected experiments at WDM channel rates up to 40 Gbit/s, taking into account various fibre types, various dispersion management schemes, various amplification methods as well as novel modulation formats. The overall goal of this collaborative research project is to provide robust design solutions with realistic tolerances for national and pan-European ultra-high capacity networks.

WDM system testbed for novel network applications: 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 Gbit/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 include transmission fibres, optical amplifiers, and means for chromatic dispersion compensation. The transmission fibre for the 10 Gbit/s channels is 80 km of standard SMF, and is compensated for dispersion using dispersion-compensating fibres.

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. The dynamics of Raman-amplified links have been investigated in the cases of switched data signals (burst-mode traffic) and switched channels to verify the properties of these links in reconfigurable networks and with discontinuous data streams. These links have been compared to those using EDFAs. The observed signal power peaks, caused by amplifier saturation effects, show that distributed Raman amplification generates significantly lower power peaks than EDFAs if signals are switched, even in the case of numerous (e.g. 50) cascaded amplifiers. To evaluate long-haul all-Raman amplified WDM systems, a switched transmission simulation has been performed in our ring network. The switching-induced signal power peaks of the 65 cascaded distributed Raman amplifiers in the 2600 km link are only 2.4 times larger than the steady state signal power. Thus, using Raman amplification only a moderate amount of gain control is needed to compensate for signal power variations.

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 being tested that allow simultaneous identification and performance control. Two concepts combining a 50 Mb/s control channel and a 10 Gbit/s payload channel were found to give good correlations between the two channels, as required for performance control, and to give error-free transmission in both channels up to distances of 2500 km.

Network and subsystem simulation and 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. The limitations due to noise and crosstalk of the size and cascadability of switching nodes for optical burst switching (OBS) are being simulated and analysed. 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) to perform these simulations.

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, as well as 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.

The performance of highly dynamic optical switched networks and the interaction of different protocol layers are being investigated using "OPNET Modeler", a simulation tool to design and study communication networks, devices, protocols, and applications. Optical burst switching is a promising candidate for a more dynamic optical layer in the next generation Internet. Therefore the IP throughput of OBS networks will be simulated and compared with that of traditional IP networks.

Transinet – Innovative transport networks for the broadband Internet: The objective of this joint project, which was begun in 2000 together with T-Systems Nova and partners from universities, 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, network management, resilience, and the interworking and integration of high-speed photonic and mobile communication systems. At 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. Furthermore, 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.

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 network 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.

Upgrading of basic network topologies towards switchable WDM networks is planned. 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 are being simulated and tested in the WDM testbed.

Access and Customer Network

Broadband access and in-house networks are prerequisites for both business and private customers for future multimedia Internet communication. Current solutions for providing capacities of more than 100 Mb/s to residential customers and up to several gigabits per second to business customers and enterprises are too expensive in both installation and operation, and are not ready for volume production.

BaiNet – Optical broadband access and in-house network architectures: This new project aims to create solutions for cost-efficient optical access and in-house networks, including wireless extensions to mobile broadband terminals for indoor applications. In close cooperation with two industrial partners, network concepts and solutions will be

developed and investigated by simulations and experiments, especially the technical and economical issues, with emphasis on operator and customer requirements.

Monolithically integrated laser components for optical transceivers: The bidirectional optical transceiver is a key component for the realization of optical subscriber links. Since they are required for cheap and reliable subassembly, recent work has focussed on the development of Fabry-Perot laser OEICs with integrated laser resonators, field transformers to reduce the numerical apertures, and integrated 45° mirrors. Several wafers have been processed successfully and about 100 chips have been forwarded to the industrial partner for assembly and reliability tests.

Another concept for hybrid structures relies on lasers and semiconductor optical amplifiers combined with waveguide structures in silicon-on-insulator (SOI). Large refractive index steps in the SOI will enable very compact structures. The challenge for the development of the InP-based lasers is the monolithic integration of proper spot size transformers and the realization of geometrical structures supporting passive hybrid mounting (with low losses and high positioning tolerances).

10 Gbit/s lasers and detectors: With the further deployment of metropolitan and access networks in the coming years, a mainstream product for fibre optics networks will be 10 Gbit/s transceivers. A crucial component in such a device is the laser. The performance requirements are extremely demanding in terms of current and power consumption, behaviour at high temperatures, large signal modulation characteristics, fibre coupling efficiency and alignment conditions, cost issues, and aging characteristics. To this end, optimization of InGaAsP/InP BH lasers has continued. 1.55 µm FP devices incorporating a spot-size converter in the form of a tapered active stripe largely meet these demands. 1.3 µm lasers were also developed. The active tapered stripe design could also be successfully adapted to DFB lasers, thanks to the development of a special e-beam writing strategy to generate continuously chirped gratings. In addition to InGaAsP-based lasers, 1.3 µm RW structures with an InGaAlAs active medium have been developed to further improve the high temperature characteristics. Superior threshold current densities of below 50 A/cm^{-2} per QW layer were achieved with this material. The activities with discrete transmitter lasers are complemented by a PhD thesis on vertical cavity lasers that focusses on the use of oxidized mirrors.

Equally important for such transceiver modules are low-cost photodetector devices, which have to fulfil stringent demands with respect to responsivity, bandwidth, dark current, long-term stability, and ease of chip mounting and fibre-chip coupling. Therefore the development of bottom-illuminated InGaAs/InP pin photodiodes for the 1.3 µm wavelength has been started. These include an integrated biasing network and are suitable for flip-chip bonding on a silicon bench. For photodiodes with a rather large active area diameter of 32 µm, which is necessary to provide sufficiently wide alignment tolerances during flip-chip assembly, a 3 dB bandwidth of 13 GHz and a high responsivity of 0.9 A/W were obtained. Further developments aim at the monolithic integration of the photodetector with a transimpedance amplifier and the extension of the receiver data rate towards 40 Gbit/s. In addition, top-illuminated photodiodes for a wavelength of 1.06 µm were fabricated for applications in optical satellite communication systems operating at 10 Gbit/s.

Microring structures: Microrings are building blocks for various optoelectronic devices such as filters, tunable dispersion compensators, ring lasers and wavelength converters. Ring radii are typically in the 100 µm range and ring structures are frequently combined with monolithically integrated gain sections (SOAs), primarily to ensure sufficiently low total device losses. High photon densities in such ring structures are particularly favourable for wavelength conversion based on four wave mixing, and corresponding experiments have been successfully completed.

WDM filter components: Polymer-based components are generally attractive because of their low-cost potential. Last year we introduced an all-polymer AWG device that features an extremely low temperature dependence of the operating wavelengths ("athermal" AWG). This work has been continued to explore a suitable technological method for wavelength trimming. Exposing the polymer chip to gamma rays proved to be a viable technique.

Another activity that relies on polymer materials is the development of an optical add-drop multiplexer (OADM) in which AWGs and switches will be used as building blocks.

An innovative, very compact OADM architecture featuring low optical crosstalk has been designed. A novel triazinacrylate-based polymer material was used. This was developed by the collaborating partner FhG-IZM and is characterized by an optical loss level of 0.4 dB/cm.

The combination of polymer and silica waveguides offers the advantage of using the silica for the low-loss transport of light and the polymer for efficiently performing switching functions. This technology, introduced a couple of years ago, is now being used to implement chromatic dispersion compensators for 10 – 40 Gbit/s systems. Microring resonator structures for this purpose were successfully fabricated and characterized.

Work on an optical beamformer PLC chip was continued, using the conventional silica-on-silicon materials platform. This chip is used to optically control the beam characteristic of a smart 60 GHz microwave antenna. In the reporting year the optical phase control and the optical amplitude control sections, which were previously implemented as two separate chips, were successfully integrated onto one 8-channel chip in order to achieve a much more compact structure.

Enabling Technologies for Future Photonic Network Components

Ultra-fast optoelectronic materials: Long-term roadmaps for optical fibre transmission systems predict transmission rates in the terabit per second range (for one wavelength channel) in the next decade. To accomplish this goal, much basic research still needs to be done to realize the required ultra-fast components. This includes particularly a search for suitable materials. Attractive candidates to exploit inherently fast intrasubband transitions are the InGaAs/GaAlAsSb QW materials on InP. Established devices (at wavelengths much greater than 2 µm) relying on such effects are quantum cascade lasers. The goal of our work is to shift the operating wavelength into the 1.55 µm range using the Sb-containing QW mentioned above. Other conceivable devices, apart from lasers, are ultra-fast optical amplifiers and all-optical switches. So far MBE-based InGaAs/GaAsSb MQW layers of high quality have been developed.

Photonic crystals: Photonic crystals are exciting new materials in photonics, and apart from the corresponding fibre structures ("holey fibres"), photonic crystals are still at the stage of fundamental research. HHI is active in this area using both the InP and the silicon-on insulator (SOI) material systems. Most challenging to achieve is the periodic structuring, with lateral dimensions in the 100 nm range and etch depths about one order of a magnitude larger, and with a sufficiently high degree of regularity to ensure moderate overall propagation losses. Corresponding two-dimensional structures have been fabricated in GaInAsP/InP as a preliminary step towards planar devices such as waveguides, bends and splitters. Waveguide structures in SOI have also been realized.

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 and 40 Gbit/s per channel) and the corresponding measurement methods

Investigation, design and development of optical WDM LANs and 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, hybrid 3R signal regeneration and add/drop techniques

Development of methods for purely optical clock recovery at bitrates of 10 to 160 Gbit/s

Development of ultra-fast switching devices based on SOAs for bitrates of 10 to 160 Gbit/s

Development of circuit architectures and of photonic components for all-optical 3R signal regeneration

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 up to 320 Gbit/s

Optimization of methods of dispersion management

Design and development of optical frequency reference equipment

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

Development, fabrication and characterization of fibre optic components

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

Development, fabrication and characterization of opto-electrical components and photonic integrated circuits based on InP and "passive" materials:
- 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
- Top and bottom illuminated 10 Gbit/s photodetectors
- 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 monolithically integrated pulse sources
- Optic/microwave converters

Polymer-based thermo-optic switches, switch matrices, and filters

Optical components based on mixed polymer/silica technology

Planar waveguide components on SiO_2/Si and SOI

Diffractive optical components

Photonic crystals

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) 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

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, improvement of the spectral efficiency of UMTS is essential to increase the overall system capacity and to give an acceptable return on investment within reasonable time spans. Therefore smart antenna systems, multiuser detection principles and advanced scheduling algorithms to improve the spectral efficiency of UMTS are being investigated. Strategies are also being developed that allow for the strongly asymmetric traffic of future services, such as IP over wireless, and to achieve the potential gains of cooperative systems.

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 multiuser 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. Starting from the basics of information theory, new results concerning the duality between downlink multiplexing and uplink multiple access have recently been obtained. The transmit strategy for the downlink has been thoroughly discussed and a highly competitive array processing algorithm balancing the signal-to-noise ratios at different terminals at a minimum cost of transmitter power has been patented. The algorithm is also efficient for heterogeneous user distributions.

Compared with the conventional matched filter receiver, a multiuser 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 small channel estimation errors. Hence we have been active in the design and allocation of spreading and training sequences to achieve the best performance of CDMA-based mobile communication systems.

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 with the same carrier frequency, 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. Several sets of algorithms and hardware architectures for multiple-input multiple-output (MIMO) channel estimation and for signal recovery in various 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.

In order to improve the performance, methods that can make use of channel state information (CSI) at the transmitter have been particularly investigated. The capacity

of a multi-antenna system may be increased even with partial CSI at the transmitter. Optimal transmission methods with covariance feedback have been investigated and the tradeoff between spatial multiplexing and diversity with covariance feedback has been analyzed. Note that WLANs operate in the time-division duplex mode, where full CSI for the down-link may be obtained from the up-link due to reciprocity. The patented concept was therefore based on linear channel inversion, which needs a simple matrix-vector multiplication at the transmitter in order to de-correlate the signals at the receive antennas. In cooperation with MEDAV GmbH, a large number of broadband MIMO channel measurements with up to 16 antennas at both the transmitter and receiver have been recorded at 5.2 GHz in order to evaluate the potential of MIMO for WLAN applications in indoor and close-to-indoor urban outdoor environments.

The result was that, with proper antenna design, very high spectral efficiencies, close to those obtained with independent Rayleigh fading (above 80 bps/Hz at 20 dB signal-to-noise ratio with 16 transmit and 16 receive antennas), are indeed achievable, since the Rician factor is rather small in those environments; i.e. the scattering is significant. It became clear that the antenna design has a significant impact on the achievable capacity, particularly in outdoor environments. The main factors influencing performance have been investigated experimentally.

Although much can be done at the antennas to increase the capacity, sometimes the capacity may actually be reduced, especially if there is little scattering. This corresponds to a low effective rank of the MIMO channel matrix. Signal processing must be more adaptive to transmit the data more reliably in this case. A new patented system concept based on linear matrix-vector operations at both the transmitter and receiver was therefore developed, called adaptive channel inversion. The main idea is to maximize the throughput by matching the number of parallel data streams to the effective dimension of the signal space. In this way, reliable operation in all kinds of MIMO channels becomes possible, and the signal processing load remains reasonable. Experimental work is now concentrated on the implementation of a demonstration system based on a hybrid FPGA/DSP approach.

In addition, a patented technique for joint space-time equalization of MIMO channels with minimal effort has been developed and an iterative algorithm for joint detection and channel estimation in MIMO systems using space-time codes has been proposed. The potential of MIMO in multiuser scenarios is also being investigated. There are still several open research problems, one of which is the issue of fair scheduling between the users. An algorithm to optimize the sum rate in the uplink has recently been found.

Recent research is also concerned with cooperative concepts in wireless communications. At the borders of a WLAN cell, for instance, transceivers might get access to the network by using transceivers inside the cell. Thus the coverage area may be increased, but the effects on capacity and energy consumption are still an open issue. The potential of cooperative techniques is presently under evaluation using a system model similar to MIMO.

The combination of OFDM and smart antennas (MIMO-OFDM) turns out to be a promising candidate for future fourth generation mobile systems, since it promises 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, with 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.

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 at 5.2 GHz and at 60 GHz. For commercial system appli-

cations we are developing calibration algorithms that are based on efficient mathematical and computational methods.

Smart antennas in the 60 GHz range will play an important role in future mobile communication systems at data rates of 155 Mbit/s and above. The generation and distribution of the microwave signals, and also beamforming, was carried out using optical microwave technology. Constrained beamforming was accomplished by a newly developed beamforming network based on SiO_2/Si. The beamformer and the beam steering algorithms were tested in an experimental system, and several experiments have been successfully carried out. The RF properties of the phase and amplitude sections of a 4-channel beamformer were measured at 60 GHz 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 optimize their performance. Fixed and mobile broadband radio access scenarios 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 digital signal processing 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.

plemented and tested under real-time conditions. It is now running successfully as an experimental prototype platform, and includes technologies for multi-view capturing, foreground/background segmentation, tracking and segmentation of hands, disparity estimation, 3D view combining, 3D warping, 3D view synthesis using image-based rendering, vision-based head tracking, hybrid 3D composition, and rendering of the virtual conference scene.

- The prototype platform is based on a conventional PC architecture, augmented by multi-DSP VPS (VIRTUE Processor Station) boards, which were developed in the Image Processing Department of HHI. The objective of the VPS board is to achieve real-time 3D video processing with state-of-the-art PC technology. When combined with an SDI interface board, up to four video streams can be captured and processed simultaneously without loading the PCI bus. Cascaded VPS boards can be used to set up an arbitrary multi-processor topology for complex 3D video processing applications.
- A second-generation prototype has been developed within the ITI project. The objective of this re-design is to achieve full MPEG-4 compliance, including BIFS scene representation, MPEG-4 video encoding and decoding and DMIF conference management. The 3D video processing chain will be optimised to reduce complexity and the number of DSP boards. ITI will target the problems of audio delay and echoes, using an integrated audio capturing, rendering and echo cancellation system based on low delay ASIO interfaces, which are generally used in professional audio recording equipment.
- The prototypes will be demonstrated to the public for the first time at an ITG workshop on "Immersive Communication and Broadcast Systems" (ICOB'03) in January 2003 in Berlin, jointly organised by HHI project ITI and the IST projects VIRTUE, ATTEST and Eye-2-Eye. A further demonstration is planned for CEBIT 2003 in Hannover.

A similar 3D video conferencing approach is being investigated in the newly established BMBF-funded VisionIC project. Together with Infineon AG, Munich, an "Advanced Videophone" is being developed that allows multiple participants to communicate in a shared virtual environment. In contrast to VIRTUE, the system is entirely avatar-based and targets extremely low bit rates (a few kilobits per second). For the description of the virtual scene and the animation of the characters, the MPEG-4 syntax is used to achieve standard-compliant virtual conferencing. Since no video stream but only 3D motion and animation data are transmitted, even low bandwidth channels, such as wireless channels for portable devices and PDAs, can be supported. A first demonstration of this system is planned for CEBIT 2003 in Hannover.

Digital Cinema (D-Cinema) is currently attracting increased attention. In contrast to the video, audio and internet industries, in which signals are now processed entirely digitally, the cinema industry seems to have lost the connection to modern technology. One reason for this stagnating development is the unavailability of several key components because of their very high technological requirements. To close the gap between traditional cinema and the new digital multimedia evolution, the D-Cinema project was started. It aims to find out how to use digital technologies and their advantages in cinema. Digital cinema will also be able to show live events such as the Olympic games or great performances, which is a completely new service. In this context the image processing department of HHI is mainly working on the distribution and receiving part of the digital cinema system chain.

- A prototype system for the immersive projection of ultra-high definition vision has been developed for digital cinema applications. The system allows the modular configuration of multiple synchronised projectors, each working in HD resolution. For immersive projection purposes, the different HD views are seamlessly stitched together.
- A new method based on MPEG-2 for the precise synchronisation of the various projectors has been developed. This synchronisation procedure is completely modular and enables the unrestricted cascading of multiple projection arrays.
- The prototype has been demonstrated at the CeBit Exhibition 2002 in Hannover, at the 20th FKTG-Meeting in Zürich, and at the IBC fair 2002 in Amsterdam.

3D-TV is expected to be the next major evolution in the history of television. So far, almost all approaches are based on the basic idea of "stereoscopic" video; i.e. the capturing, transmission and display of two separate video streams, one for each eye. The main drawback of these systems is their inflexibility in terms of depth reproduction as well as different display technologies and viewing conditions. A new approach, currently under development within the IST project ATTEST,

tries to overcome these restrictions and provide a more flexible system. The concept is based on the joint transmission of video and associated depth information. Monoscopic or stereoscopic "virtual" views of the scene are generated by means of depth-image-based rendering techniques. The following results have been achieved so far:

- The ATTEST 3D-TV scenario was proposed for evaluation by the newly established MPEG 3D Audio/Visual Ad-Hoc group. It was accepted as an interesting future 3D technology.
- First experiments on the coding of depth information have been carried out by ATTEST and MPEG. Preliminary results suggest that only minor extensions to the current MPEG standard are necessary to enable a 3D-TV broadcast service based on the ATTEST concept.
- A 3D renderer capable of synthesising stereoscopic views for different 3D displays is currently under development. The system supports head-motion parallax viewing and will provide the 3D-TV user with the possibility of adjusting the depth perception to meet his or her own preferences. It will also support various composition algorithms (CRT space only, CRT plus viewer space, or zero-parallax setting defined by the content provider).

Mobile multimedia is foreseen to be one of the major applications for the upcoming broadband mobile networks such as UMTS. Besides pure streaming applications for unidirectional communication, bi-directional applications such as video teleconferencing and multimedia messaging will become more and more popular.

- To fulfil the special requirements of multimedia applications in mobile environments in terms of power dissipation and processing power, a dedicated MPEG-4 video codec ASIC has been implemented in cooperation with an industrial partner. This ASIC, which is based on several hardware acceleration components and an embedded processor, is a complete single chip solution for MPEG-4 video coding and decoding, and has picture resolutions up to QCIF at 15 fps and data rates up to 128 kbit/s. The hardware-software partitioning was based on the results of intensive profiling runs using optimised MPEG-4 video codec software for the targeted ARM processor core. The whole software was implemented from scratch using C. The software supports MPEG-4 simple profile at levels 0, 1, 2 and 3, which differ slightly from each other in the tools used. From the specifications of the target application, the highest supported bitrate of 128 kbit/s for QCIF resolutions with frame rates of up to 15 frames/sec was chosen for the profiling runs. Based on this analysis, the deblocking and deringing filters as well as the colour conversion and image scaling sections were chosen to be dedicated hardware blocks in the decoder. On the encoding side, the motion estimation was identified as a candidate for dedicated hardware implementation.

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 to 96 kHz and provides audio of near CD quality at a very low bitrates (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.

- The availability of powerful DSP and RISC processors enables the implementation of complex audio codecs on dedicated modules in hand-held devices. MPEG-4 AAC audio encoders and decoders for real-time applications have been implemented on different platforms: Texas Instruments DSPs, RISC processor StrongARM, and MIPS32 4Kc. The performance and low power consumptions of these processors enable the implementation of modules for battery-powered hand-held systems.

Novel multimedia terminals and interactive applications need the simultaneous display of several sources on one display. Under the framework of the KOKON project, funded by BMBF, the DUMA (multi-standard display unit) board was developed as a hardware platform for applications requiring simultaneous display of different videos and computer-generated images. Composite (FBAS) or component analogue and digital (DVI) signals are supported as input standards. The system is able to display up to four real-time video images or pictures on a high-resolution monitor using digital (DVI) or analogue (RGB) inputs. The windows can be independently positioned, alpha-blended, or overlaid with other windows. A hardware-supported cursor can be used for navigation purposes.

- The implementation of the system on an FPGA platform, using a StrongARM module

for processing control, has been completed. The system will be presented at an HHI workshop in March 2003.

Conversion from one video format to another (e.g. TV to HDTV) and image enhancement are two very important techniques for advanced multimedia terminals. In the field of format conversion, HHI has established trend-setting know-how and expertise in numerous research activities. The motion compensating image sequence conversion algorithm (HiCON), developed by HHI, provides conversion between different image sequence formats. It performs de-interlacing while preserving full spatial resolution. Image rate conversion is accomplished with sufficient motion portrayal for high-quality image applications such as digital cinema. This is the basic requirement for the optimal flicker-free and judder-free operation of high-end displays. HHI performed architectural studies on the basis of motion-compensated video image conversion techniques. Both a software realization and a single chip realization have been developed.

- The software implementation is suited for the conversion of all standard video and graphic formats. It is projected as an off-line platform-independent software tool, but so far is optimised for win32 applications. This software will by marketed by an industrial partner.
- The design of a single–chip implementation for real-time applications in standard TV and HDTV is complete. The netlist has been simulated and may be transferred to silicon. This design is the basis of several cooperative industrial ventures planned for 2003.
- Several image enhancement algorithms that reduce blocking and ringing artefacts caused by standard codecs (e.g. MPEG-2) have been investigated. A real-time deblocking filter has been implemented and optimised on the Trimedia DSP.

Advanced multimedia applications are becoming more and more complex. Hence reusable, modular and well-designed software must be used to create stable, maintainable and supportable applications.

- During the last year, the Image Processing Department established software design procedures that ensure cost-effective software development, that protect HHI's intellectual property, and that reduce the time to market. A project group was founded to create a documented, guided and supported process for the generation of applications and libraries that meet the above requirements.

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 teleimmersion 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 such diverse areas as 3D telephony and video conferencing, 3D TV, 3D multimedia desktop computing, mixed-reality worlds, telepresence, telework, telesupervision, vehicle navigation and driver assistance 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 parallax barrier screens, lenticular lens screens and field lens technologies. Prototypes of these developments were introduced to the public this year at the CeBIT 2002 in Hannover and at several smaller trade fairs and exhibitions.

- A high resolution single-user autostereoscopic 20.1'' flat panel display for use in the CAD/CAM area was developed. This display provides (2 x 512) x 1280 pixel resolution and does not require mechanical tracking of the lenticular screen – instead, the entire monitor is mounted on a mechanical tracking platform so that the image plane can track the user's head movements (Face-to-Face 3D Display concept). Optionally, an IR head tracker in combination with pixel switching technologies gives the user tracking comfort when moving in front of the screen. Based on a license agreement with the HHI, A.C.T. Kern GmbH & Co. KG, a

renowned manufacturer of professional displays, has recently started production and sales of this novel display system.

• We have developed a special 2D/3D compatible version of this type of display called CabrioScreen. The CabrioScreen is a 3D add-on, including a removable lens plate and a high precision IR head tracker, that allows the user to temporarily convert a common 20.1'' NEC LCD display into a high-resolution autostereoscopic display.

• Various newly emerging mixed-reality applications, e.g. in the automotive sector, require a wide screen display, in order to show extended portions of a large system in natural size. On the other hand, designers want a means for precise 3D visualization and manipulation of selected parts of the components under development. For this purpose, we have developed the Hybrid Display, a unique precision 3D display embedded in a large surrounding 2D display area. The displays share a joint 3D data space. With a simple hand gesture, detected by a video tracker, the user can select a part of interest from the 2D area and move it focus on the 3D display (gesture-based drag & drop operation 3D), where it will float 20 cm in front of the display screen. The user may then touch it like a real object. The current finger position is remotely detected by a stereo hand tracker embedded in the desktop. Optionally, a force feedback device provides tactile feedback when touching the virtual object with a (simulated) tool.

• The Accommodation Display is a novel autostereoscopic single-user display based on a special 3D technology using a large-diameter field lens. With this display it is possible to create an aerial stereo image plane appearing at any position, either in front of the display (e.g. within reach) or behind the display screen. The display has outstanding resolution, brightness and contrast and minimal crosstalk (far below the visibility threshold). It is particularly useful for mixed-reality applications, since it is possible to make the accommodation distance of a virtual object perfectly match the distance of a real object (e.g. of a tool used to manipulate the virtual object). This contrasts with conventional 3D techniques, which are known to produce conflicting accommodation stimuli when users try to directly touch 3D objects appearing stereoscopically in front of the display.

• A large format 40'' autostereoscopic back projection display with high resolution ((2 x 1000) x 750 pixels) was developed for applications in multimedia desktop computing. This monitor features mechanical tracking of the parallax barrier screen.

• New developments focus on a combined 2D/3D display with lenticular lens tracking for 3D TV and kiosk applications. In this case the 2D area is designed as a touch screen, which may for example find application as a user interface for searching for additional program information over the internet (TV application) or for browsing an electronic catalogue (kiosk application). We have also started to extend the Accommodation Display principle to the development of virtual and mixed-reality displays for mobile applications.

• A video-based head tracker compatible with a range of low-cost as well as high-precision cameras was developed so that the HHI displays can be used without special glasses.

• A recently patented 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 a simple means for the user to interact with it. In contrast to conventional windows-based desktops, this operating system is object oriented and can layer information in the depth dimension.

• A 20'' high-resolution autostereoscopic display that was developed by 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 (motion parallax).

- A novel workbench system based on Windows XP allows simple user interaction with multiple 2D and/or 3D display screens of various formats in a joint data environment. The HHI Workbench accepts input from multimodal interface devices, such as the head, eye or hand movement trackers that have been developed in our labs, and will be used in connection with the Hybrid Display for mixed-reality applications.
- An improved video-based method for 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. We have implemented a user-friendly (automatic) initialization and calibration process for both trackers.
- A stereo video hand tracker was developed for novel man-machine interaction applications. This device is able to track hands or fingers, so that the user can point to and interact with virtual objects floating in front of a 3D display 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, gaze and hand-gesture 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 tracking algorithm responds reliably to the smallest changes of head position, even in difficult lighting conditions, and passes the measurements to a head tracking display or to another device controlled by the head position. The algorithms work in real time and were implemented under Windows 2000 and XP. The tracker software can be used in connection with a wide range of cameras using standard WfV and WDM video drivers as well as special drivers delivered with the camera. Several head-position data output formats are supported (DCOM, RS232, UDP). Measurement rate is up to 120 Hz, so that there is no noticeable delay.
- We have developed and recently patented a multiple-cornea-reflex technique to measure the gaze direction. When used with the video head tracker, this technique allows free head movements. Gaze-direction measurements are also being investigated for possible use as input signals 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 are the identification of users, the sensing of their interactions with others, the sensing of their emotions or communication readiness, 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 in-

dividual 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.
- 3D visualization tools were developed that enable the user to search and navigate intuitively through an image database. This approach is based on a new relevance feedback technique.
- 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.
- A new similarity measure for segmented images was developed. This method takes into account colour, edge, texture and shape properties of image segments as well as their relative positions.

In a new research effort initiated in 2002, we are extending this work to the search and archiving of digital video content. In particular, we are developing methods for the segmentation of video sequences, algorithms for the MPEG-7 conformant extraction of video descriptors, algorithms for semantic classification of video sequences as well as a user interface for intuitive visualization of video data spaces and content searching. This research is performed in cooperation with national and European consortia, including partners from universities and relevant industrial enterprises.

Another new research project is focusing on the development of a novel platform to support mobile services for citizens. This work aims at achieving the full functionality of the common stationary services. Among other things, the project is conducting research into the security and usability aspects of the mobile hardware, software and data transmission components. The system will be tested under controlled conditions in the laboratory as well as in extended field trials. The Senate of Berlin is one of the partners in this project.

Competencies

3D image and video processing

Image and video coding (MPEG-1/2/4, H.26x, wavelet and model based)

Image and video analysis, computer vision

Image and video synthesis, computer graphics

Multimedia transmission (IP, mobile networks, DVB)

Hardware design and implementation of multimedia systems (video, audio, graphics)

ASIC and IP design

Image and video enhancement (format conversion, noise reduction, deblocking, deringing)

Immersive image reproduction techniques

Multiview capturing and display systems

Software design and implementation of multimedia systems

Autostereoscopic 3D and mixed-reality displays for desktop and mobile applications

Human-computer interaction

User interface development, including 3D GUI design and techniques for multimodal interaction (head tracking, gaze tracking, hand tracking and gesture recognition)

Application development with Visual C#, Visual C++ and Java; expertise in multimedia application programming using DirectX

Usability engineering

Image and video segmentation, feature extraction, classification, retrieval and archiving

Video-based pattern recognition and photogrammetry methods

User and object sensing and tracking methods, including inside-out and outside-in optical tracking techniques

Analysis of human sensory and sensorimotor functions in relation to multimedia applications

R & D PROJECTS

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
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 3/02 – 5/04
System Aspects and Tests for Cityring Networks	Ernst-Jürgen Bachus +49(0)30-31002-586 bachus@hhi.de	BMBF/Industry (KomNet) 9/98 – 12/02
Design of Switchable Optical Networks	Ernst-Jürgen Bachus +49(0)30-31002-586 bachus@hhi.de	BMBF (UMTS) 4/01 – 3/03
Development of Optimised Expanding Strategies for Wavelenght Division Multiplex System for Applying a maximum Transmission Datarate in Modern Fibre Infrastructures	Ernst-Jürgen Bachus +49(0)30-31002-586 bachus@hhi.de	BMBF (MultiTeraNet) 10/02 – 9/04
Control Modulation Technique for Client-Independent Performance Monitoring and Channel Identification in Transparent Optical Networks	Ernst-Jürgen Bachus +49(0)30-31002-586 bachus@hhi.de	DFG 10/02 – 9/04
Broadband Optical Access- and Inhouse Networking – Network Architecture and Protocols (ON)	Klaus Langer +49(0)30-31002-457 langer@hhi.de	BMBF (MultiTeraNet) 10/02 – 9/05
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	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 – 4/04
Gain-Clamped Optical Amplifier in Fibre-optical Transmission Systems	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.de	DFG 4/98 – 6/04
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 – 2/03
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
Optical Time Division Multiplex Techniques for 160 Gbit/s and 640 Gbit/s	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.de	BMBF (MultiTeraNet) 01/02 – 9/05
Transmission Techniques in a Single Channel for Datarates of 160 Gbit/s and beyond	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.de	Industry 11/01 – 3/03
Integrated Circuits for a ETDM-Datatransmission in a 80 Gbit/s Single Channel	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.de	BMBF 1/01 – 12/03
Compression Techniques and System Investigations	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.de	State of Berlin 9/02 – 8/05
Transfer 40 GHz Optical Clock	Bernd Sartorius +49(0)30-31002-508 sartorius@hhi.de	Industry 4/02 – 3/04

High-frequency Selfpulsation of Multi-section DFB Laser	Bernd Sartorius +49(0)30-31002-508 sartorius@hhi.de	BMBF 2/01 – 7/03
Terabit per Second Optical Transmission Systems Based on Ultrahigh Channel Bitrate	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
Design of Switching Characteristics in Dispersive Q-switch Semiconductors	Bernd Sartorius +49(0)30-31002-508 sartorius@hhi.de	DFG 2/01 – 6/02
Technical Development for OTDM Demultiplexers	Michael Schlak/Bernd Sartorius +49(0)30-31002-407/-508 schlak@hhi.de/sartorius@hhi.de	HHI 1/98 – 12/02
160 Gbit/s 3R Regenerator	Michael Schlak +49(0)30-31002-407 schlak@hhi.de	Industry 11/01 – 6/04
Development of DFB-BH-Lasers	Martin Möhrle +49(0)30-31002-724 moehrle@hhi.de	Industry 1/01 – 3/02
Development of Future InP-based Laserdiodes	Martin Möhrle +49(0)30-31002-724 moehrle@hhi.de	State of Berlin IBB 1/02– 12/03
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
Monolithically Integrated Picosecond Pulse Source	Helmut Heidrich +49(0)30-31002-538 heidrich@hhi.de	BMBF 10/00 – 9/03
Hybrid Integration on SOI Basis/ adapted Laser and SOA-OEICs	Helmut Heidrich +49(0)30-31002-538 heidrich@hhi.de	BMBF (MultiTeraNet) 10/02 – 9/06
Planar Photonic Crystals in Materialsystems with high Index Contrast	Helmut Heidrich +49(0)30-31002-538 heidrich@hhi.de	BMBF/VDI 2/02 – 1/05
Realisation of high Order Optical Filters Using Active Coupled Microring Resonators	Helmut Heidrich +49(0)30-31002-538 heidrich@hhi.de	DFG 11/01 – 10/03

BH-Laser for High Bitrates	Jochen Kreißl +49(0)30-31002-525 kreissl@hhi.de	HHI 1/02 – 12/02
Semiconductor Saturable Absorber Structures for Femtosecond demultiplexer	Harald Künzel +49(0)30-31002-546 kuenzel@hhi.de	MBI/HHI 11/98 – 3/02
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
Intersubband Materials for Ultrahigh Speed Optical Switches	Harald Künzel +49(0)30-31002-546 kuenzel@hhi.de	Land Berlin (TOB) 10/02 – 9/05
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 – 12/02
Development of Advanced Technologies for Ultrafast Photoreceivers	Udo Niggebrügge +49(0)30-31002-550 niggebruegge@hhi.de	HHI 6/98 – 04/02
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
Electro-optical Modulator for Future Communications Networks	Karl-Otto Velthaus +49(0)30-31002-645 velthaus@hhi.de	BMBF (MultiTeraNet) 10/02 – 9/05
Development of New Concepts, Structures and Technologies in Producing Modulators for 160 Gbit/s	Karl-Otto Velthaus +49(0)30-31002-645 velthaus@hhi.de	State of Berlin (TOB) 9/02 – 8/05
Monotlithically Integrated Lightsources	Bernd Hüttl +49(0)30-31002-659 huettl@hhi.de	State of Berlin (TOB) 9/02 – 8/05
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 Photo Detectors and Receiver – OEICs	Wolfgang Schlaak +49(0)30-31002-519 schlaak@hhi.de	Industry 1/02 – 12/03
Planar Selective Epitaxie	Anagnostis Paraskvopoulos +49(0)30-31002-527 Paraskevopoulos@hhi.de	Industry 11/01 – 12/03
Development of New Lightsources; Production Processes and Fibre Couplings	Anagnostis Paraskvopoulos +49(0)30-31002-527 Paraskevopoulos@hhi.de	Industry 1/02 – 12/03
1400 nm Pump Laser Source for TDFA	Anagnostis Paraskvopoulos +49(0)30-31002-527 Paraskevopoulos@hhi.de	BMBF (MultiTeraNet) 6/02 – 5/05
Development of a Photoreceiver	Heinz-Gunter Bach +49(0)30-31002-503 bach@hhi.de	Industry 7/02 – 12/03
High Rate Optical Receiver for 80/160 Gbit/s	Heinz-Gunter Bach +49(0)30-31002-503 bach@hhi.de	BMBF (MultiTeraNet) 10/02 – 9/05

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 – 12/02
Multiuser Receiver for CDMA Systems	Holger Boche +49(0)30-31002-540 boche@hhi.de	HHI 6/00 – 12/02
Sequences in CDMA Systems	Holger Boche +49(0)30-31002-540 boche@hhi.de	DFG 7/00 – 6/02
MULTIMODE: MIMO Techniques and Antennas	Clemens v. Helmolt +49(0)30-31002-506 helmolt@hhi.de	HHI 9/00 – 12/02
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
Broadband Optical Access- and Inhouse Networking – Network Architecture and Protocols (BM)	Gerd Großkopf +49(0)30-31002-317 großkopf@hhi.de	BMBF (MultiTeraNet) 10/02 – 9/05

Electronic Imaging Technology for Multimedia

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
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
Advanced Three-dimensional Television System Technologies (TV), ATTEST	Peter Kauff +49(0)30-31002-615 kauff@hhi.de	EU 3/02 – 2/04
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
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
Programmable HYbrid TV System with Integrated CoreS, PHYSICS	Karsten Grüneberg +49(0)30-31002-262 grueneberg@hhi.de	Industry 1/01 – 3/02

Development and Implementation of Algorithms and Structures for Video Projection by LC-Displays	Karsten Grüneberg +49(0)30-31002-262 grueneberg@hhi.de	Industry 9/02 – 3/03
Integrated Hardware Architecture for Multimedia Broad Image Project/TriMedia DSP	Karsten Grüneberg +49(0)30-31002-262 grueneberg@hhi.de	Industry 9/02 – 4/03
Systems for Advanced Multimedia Broadcast and IT Services	Peter Stammnitz +49(0)30-31002-570 stammnitz@hhi.de	EU 1/00 – 04/02
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
Optimization of a Sequency Based Video Transmitting	Thomas Wiegand +49(0)30-31002-617 wiegand@hhi.de	DFG 5/02 – 4/04
Algorithms for a 3D Realtime Videoconferencing System with high Telepresence	Ralf Schäfer +49(0)30-31002-560 schaefer@hhi.de	DFG 8/02 – 7/03
Highly Efficient TV-Transmitting in the DVB-T Network of Berlin and Brandenburg	Ralf Schäfer +49(0)30-31002-560 schaefer@hhi.de	State of Berlin 10/02 – 9/03
Development of an Intelligent Vision Platform Including Pilot Applications for the Mass Market	Peter Eisert +49(0)30-31002-614 eisert@hhi.de	Industry 5/02 – 4/05
Intelligent Scalability for Interoperable Service	Stefan Rauthenberg +49(0)30-31002-266 rauthenberg@hhi.de	Industry 10/02 – 12/03
3D Techniques for Mixed-Reality Systems	René de la Barré +49(0)30-31002-345 barre@hhi.de	BMBF 1/02 – 12/04

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MPEG-7 based Analysis and Visualisation Tools for Archiving Digital Video	Thomas Meiers +49(0)30-31002-218 meiers@hhi.de	BMWi 4/02 – 3/52
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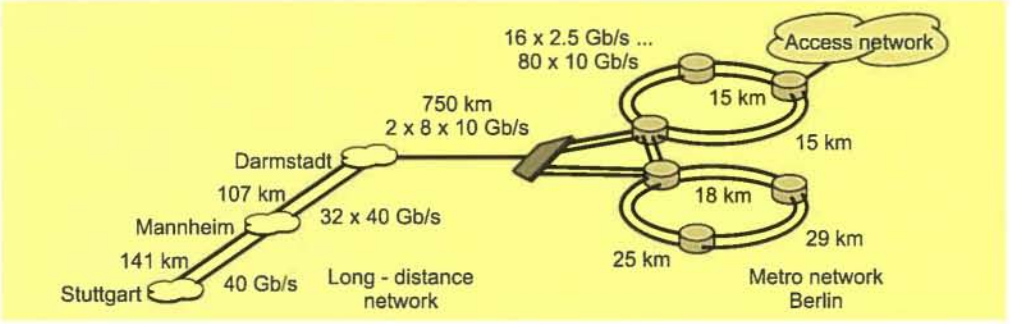
Research Initiative KomNet – Review and Final Results

Over the past four years, under the framework of the German R&D initiative KomNet, an industry-based consortium has developed enabling technologies for future multi-vendor multi-client wavelength division multiplexing (WDM) communication networks. Many excellent results were achieved. HHI contributed several R&D projects and the Systems Integration Office to KomNet.



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

A consortium of industry leaders, comprising Acterna, Alcatel SEL, Infineon Technologies, Lucent Technologies, Siemens, T-Systems Nova and VPI Systems, has collaborated with 20 research institutes, universities and SMEs to develop and field-trial optical networking technologies, network elements, components, protocols, and access network technologies [1]. Using an in-place standard single mode fibre infrastructure provided by T-Systems Nova, a complete demonstration communication network, including long distance network, metropolitan network, and several access systems, has been implemented (see figure).

Basic functions of next-generation transport systems at 160 Gb/s and WDM systems with very high capacities (up to 32 x 40 Gb/s) have been field-trialled on this platform. Dynamic adding/dropping of WDM channels, automatic switching and all-optical interconnecting of different vendor's systems have also been demonstrated. Other functions have also been trialled, including the transport of various client signals, novel routing functions, performance monitoring of WDM channels, and basic functions for network management in a multi-vendor environment. In the area of network access, hybrid fibre coax and fibre radio techniques and their key components were also developed and tested. In addition to the numerous field trials conducted individually by the project partners, 15 cross-project field trials were also conducted.

The work of KomNet was completed in 2002. Even though the systems and components were not designed for maximum demand, but for robustness and reliable operation under realistic conditions, several outstanding results were achieved, which demonstrate impressively the capability of domestic R&D in this field. The results provide a solid base for solving current tasks of product-oriented development and for further research on photonic communication networks.

As described in more detail in the following contributions, HHI was involved with several projects on the design and simulation of optical networks, the evaluation of network elements, ultra high-speed time division multiplexing transmission up to 160 Gb/s, 40 Gb/s photodetectors and receivers, all-polymer optical add-drop multiplexers, optical signal regenerators, transceiver photonic ICs, and picosecond opto-electronic ICs.

In addition, the KomNet Systems Integration Office at HHI managed the implementation of the demonstration network and the field trials. This work was supported by the industrial partners and was partly funded by the German Federal Ministry of Education and Research under grant 01 BP 805.

[1] K.-D. Langer and J. Vathke, "Overview and recent developments of the German R&D initiative KomNet", Proc. Int. Conf. Transparent Optical Networks (ICTON), Th.B.3, Warsaw (PL), April 2002.

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TransiNet – Innovative Transport Networks for the Broadband Internet

The 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 and towards packet switching.

Burst-switched optical network

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

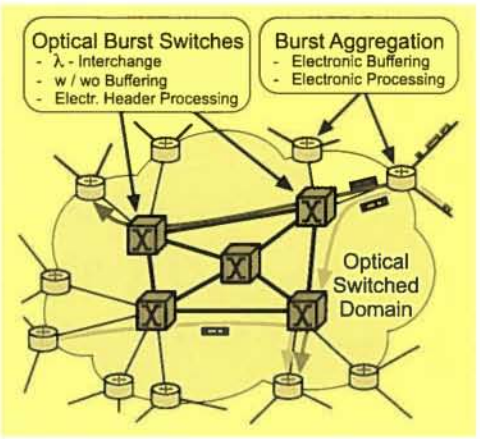
The Partners in the TransiNet project are:

- Fraunhofer-Institut für Nachrichtentechnik – Heinrich-Hertz-Institut, Berlin (FhG-HHI)
- University of Stuttgart, Institute of Communication Networks and Computer Engineering (IKR)
- T-Systems Nova GmbH, Technologiezentrum (T-Systems Nova)
- Technical University of Berlin, Faculty of Electrical Engineering and Computer Science, Telecommunication Networks Group (TKN)
- University of Technology Munich, Institute of Communication Networks (LKN)

Cooperation among the partners is organized in working groups. The focal points in TransiNet are Network Operation, Architectures, Routing and Resilience, and Wireless.

The main research areas in TransiNet for the next-generation optical Internet are new concepts for network and node architectures and their 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, mainly IP, is also being studied.

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

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

For more information visit www.transinet.de

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All-Raman Amplified Links and EDFA Links with Switched Channels

Transmission links with cascaded distributed Raman amplifiers are compared with those using EDFAs for switched 8x10 Gb/s WDM channels. The switching-induced signal power peaks are up to 50 times lower with distributed Raman amplification than with EDFAs if gain control is not used.

Distributed Raman amplification (DRA) has become very attractive in high-speed broadband WDM transmission systems, especially for long-haul transmission and low noise preamplification.

We investigated the dynamics of distributed Raman amplified WDM links and compared them with similar Erbium doped fibre amplifier (EDFA) links to evaluate the signal power responses of the channels when all or parts of the channels are switched and gain control is not used. Two 8 x 10 Gb/s WDM links were used, each with five stage amplifiers (distributed Raman amplifiers or EDFAs with 73 dB gain) and dispersion-managed 200 km fibres (Fig. 1).

Raman amplification was implemented by pumping the five fibres with Raman fibre lasers (1455 nm, 2.5 W) and laser diodes (1447 nm, 0.24 W). Channel switching and generation of data bursts (300 µs long with 10 to 1000 µs interruption times) were performed using an acousto-optical switch.

The experiments show that cascaded EDFAs generate much higher signal power peaks in switched channels (up to 50 times larger) than Raman amplifiers for long signal interruptions (Fig. 2) [1].

If the pauses are less than 60 µs, the peaks with EDFAs differ by a factor of only two from those with Raman amplifiers (Fig. 3).

For long-haul 8 x 10 Gb/s transmission over 2600 km with 65 cascaded distributed Raman amplifiers and 4 out of 8 switched channels, the signal peaks are only 2.4 times larger than the steady state signal powers. From these results and the low noise and broadband amplification properties, it can be concluded that distributed Raman amplifiers behave significantly better than EDFAs for both non-switched and switched channels and signals. This, plus the decreasing prices of the Raman pump lasers, will lead to further use of Raman amplification.

When Raman amplification is applied in the field, appropriate safety measures can be installed.

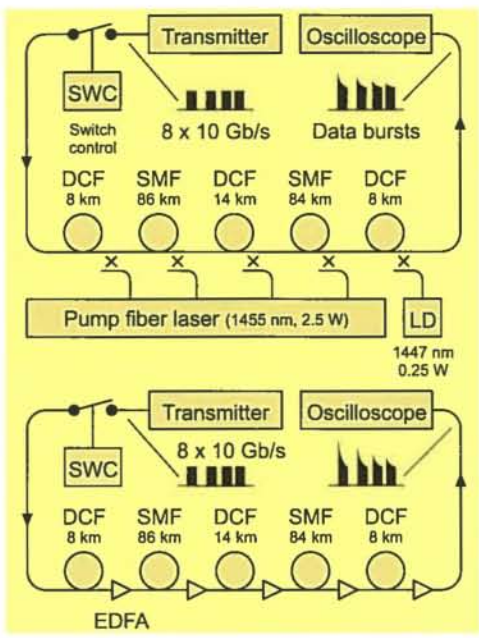

Fig. 1a: Switched distributed Raman link

Fig. 1b: Switched EDFA link

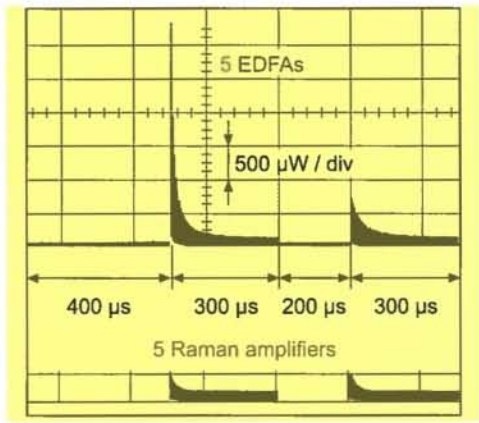

Fig. 2: Signal power peaks generated by cascaded distributed Raman amplifiers and EDFAs with switched traffic

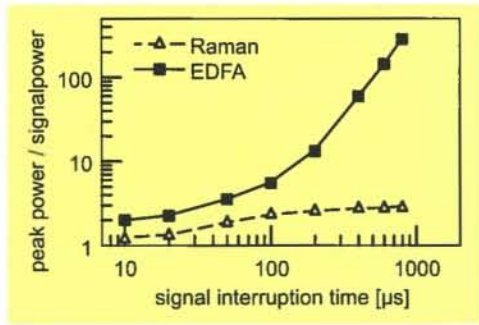

Fig. 3: Normalised signal power peaks as functions of the signal interruption time (normalised signal power peak is the ratio signal power peaks/steady state signal power)

[1] E. Schulze et al., "All-Raman amplified links in comparison to EDFA links in case of switched traffic", ECOC 2002, Symposium 3.8.

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Monitoring of Transmission Impairments in Transparent WDM Networks using a Novel Control Modulation Technique

A new client-independent control-modulation monitoring technique for transparent networks is applied to monitor client signal impairments due to noise, fibre nonlinearities and chromatic dispersion. The early warning function of the control signal for client signal degradation is demonstrated by experiments and simulations.

Optical performance monitoring is a key issue for the management of future transparent WDM networks. In a flexible transport infrastructure, the quality and switching state of a light path should be definable independent of the client signal. With the control modulation technique, a low bitrate digital control signal is physically linked to each WDM client signal by modulating the optical carrier (Fig. 1). The insertion of the control signal at the edge of the transparent network becomes client-independent by using additional optical modulation. The control signal is extracted for monitoring purposes at a network node along the light path of the client signal by power tapping and filtering (Fig. 2).

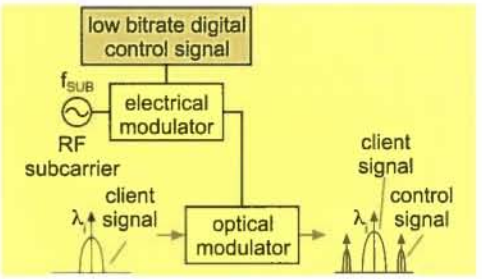

Fig. 1: Client-independent insertion of the control signal at the edge of the network

The main advantages of the control modulation technique over other performance monitoring techniques are its high flexibility and accuracy and moderate costs (only narrow-band processing is employed for the control modulation).

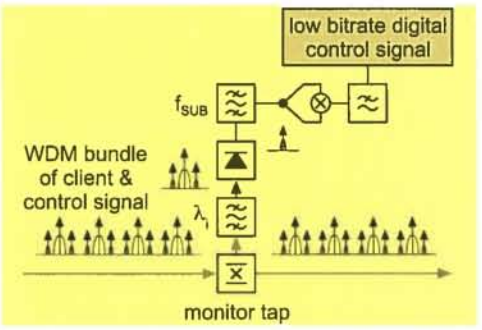

Fig. 2: Extraction of the control signal at a network node

The control signal is made highly susceptible to impairments that affect the high-speed client signals by using a high-frequency electrical subcarrier. Typical examples of impairments affecting the control signal are residual chromatic dispersion of a fibre link and distortion due to fibre nonlinearity, e.g. self phase modulation. Another important transmission impairment is the noise that is added by optical amplifiers. Figures 3 and 4 show one-channel simulation results for an optically amplified, dispersion-compensated link of 800 km length. The quality (receiver sensitivity) of a 10 Gb/s client with a 50 Mb/s control signal is displayed as a functions of either the compensation ratio or the fibre launch power.

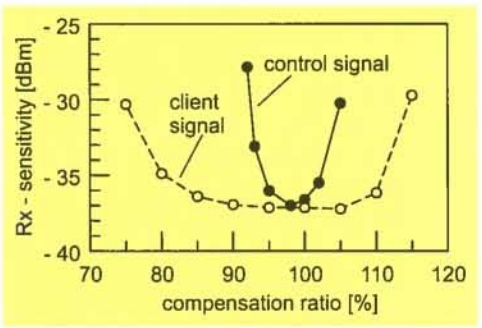

Fig. 3: Monitoring of residual chromatic dispersion

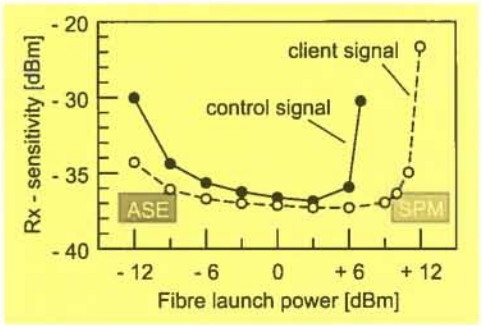

Fig. 4: Monitoring of amplified spontaneous emission noise (ASE) and self phase modulation (SPM)

The proper choice of the control modulation parameters (subcarrier frequency 9.75 GHz and modulation index 20 %) results in the desired early warning function for the client signal impairment due to fibre dispersion, amplifier noise and fibre nonlinearities.

The simulation results were confirmed by corresponding loop experiments.

[1] M. Rohde et al., "Transparent performance monitoring and channel identification by new client independent control modulation technique", Electr. Lett., vol. 38, no. 12, June 2002, pp. 587-88.

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WDM Transmission over Mixed Fibre Infrastructures

The existing global fibre infrastructure uses various fibre types, including standard single-mode fibre (G.652) and non-zero dispersion-shifted fibre (NZDSF). It is shown, by way of an example using G.652 and Corning® LEAF® fibre, that transmission over inhomogeneous network links can take place without additional penalties if the transmission performance of the individual fibre sections is optimised.

With the introduction of transparent networking, optical communication signals that pass through network links of different fibre types may show unpredictable transmission performance. For various homogeneous and inhomogeneous fibre infrastructures the overall performance of 10 Gb/s NRZ WDM transmission is investigated. Typical parameters of the fibres under investigation are given in Fig. 1.

Fiber parameters @ 1550 nm

	G.652	LEAF	DCF
Loss dB/km	0.20	0.20	0.48
Dispersion ps/km/nm	16.7	4.14	-98.3
Dis. Slope ps/km/nm²	0.055	0.085	-0.34
Nonlin. Index m²/W	$2.3 \cdot 10^{-20}$	$2.3 \cdot 10^{-20}$	$2.3 \cdot 10^{-20}$
Effective Area µm²	80	72	20
Slope Compensation	95%	16.8%	N/A

Fig. 1:
Fibre parameters

For each fibre link type, an optimised design (with regard to dispersion map and fibre input powers) was developed using extensive numerical simulations. It was found that the performance of hybrid and hybrid inverse schemes, which are both symmetrical in terms of the dispersion map (Fig. 2), is superior to that of pure post-compensation or pre-compensation schemes [1].

To verify the simulation results, recirculating loop experiments were carried out. The loop consisted of fibre links as in Fig. 2, and up to 16 channels at 100 GHz spacings were transmitted. The maximum reach for the homogeneous G.652 and LEAF links is more than 4000 km for single channels, but only 2500 km for WDM transmission over the LEAF fibre (Fig. 3). As expected, the nonlinear channel distortion [2] is higher for the LEAF link than for G.652 link due to the reduced dispersion of LEAF.

An inhomogeneous link of alternately cascaded sections was then constructed, using the optimal parameter values for the individual fibres. With this link up to 2500 km without FEC and Raman amplification was achieved for WDM channels.

These results suggest that inhomogeneous fibre sections, when individually optimised, can be cascaded trouble-free in arbitrary sequence.

[1] D. Breuer et al., Asia Pacific Opt. Com. Conf. 2001, Vol. 4584, 104-114.

[2] C. Caspar et al., OFC 2001, paper WI5.

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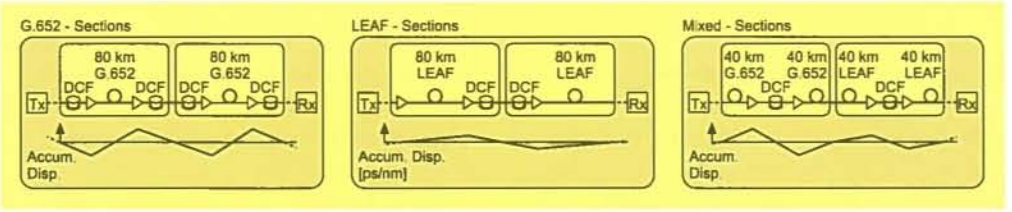

Fig. 2:
Compensation schemes with corresponding dispersion maps

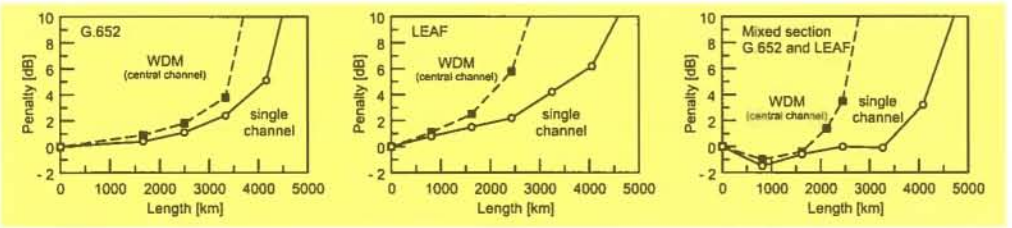

Fig. 3:
System penalty for 10 Gb/s NRZ ASK single channel and WDM experiments

Novel Slope-Compensating Optical Fibres Permits Capacity Increase for Future-Proof Long Haul WDM Systems

The upgrade of the existing non-zero dispersion-shifted fibre (NZDSF) infrastructure for future-proof broadband long haul transmission is experimentally demonstrated using a novel slope-compensating dispersion compensating fibre (DCF). For 1500 km reach the accessible bandwidth is expanded to 50 nm instead of the 7.5 nm window achieved using a conventional DCF designed for standard single-mode fibre.

During recent years telecommunication carriers have widely deployed NZDSFs for WDM long haul transmission at and beyond 10 Gb/s, where dispersion compensation is needed even for these new fibre types. Due to the reduced chromatic dispersion of NZDSFs, compared to that of standard single mode fibre (ITU-T G.652), less dispersion compensation is needed and thus there are reduced network costs. However, with the move towards ultra-long haul 10 Gb/s systems and the desire to future-proof networks for 40 Gb/s, a new generation of DCFs with dispersion slope compensation has evolved. The most widely available DCFs are optimized for G.652, particularly those designed for dispersion slope compensation. These devices, when used with NZDSFs, lead to slope mismatches that limit transmission performance and reduce the usable wavelength band [1].

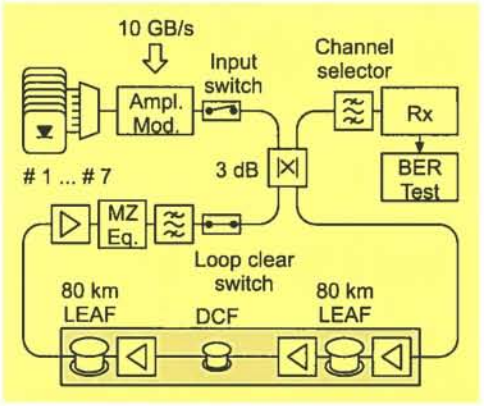

Fig. 1: Recirculating WDM loop testbed

Transmission experiments with 10 Gb/s NRZ ASK signals were carried out using a WDM loop testbed (Fig. 1) containing Corning® LEAF® fibre in combination with a novel dispersion slope compensating fibre DCF_{LEAF} optimized for LEAF. These results are compared with those obtained with LEAF and a conventional DCF matched to G.652 ($DCF_{G.652}$). Chromatic dispersion-optimized sections in which the accumulated dispersion had a symmetrical characteristic were used in the loop [2-3]. The critical link parameters are the fibre input powers into the LEAF and DCF fibres and the chromatic dispersion compensation ratio $CR = |D_{DCF}*L_{DCF}|/(D_{LEAF}*L_{LEAF})$. The experiments showed that, for a reach of 1500 km, a CR range from 87 % to 99 % is tolerable. In Fig. 2 it is seen that in this range the usable wavelength band of 7.5 nm with the conventional $DCF_{G.652}$ is increased to 50 nm when the new DCF_{LEAF} is used.

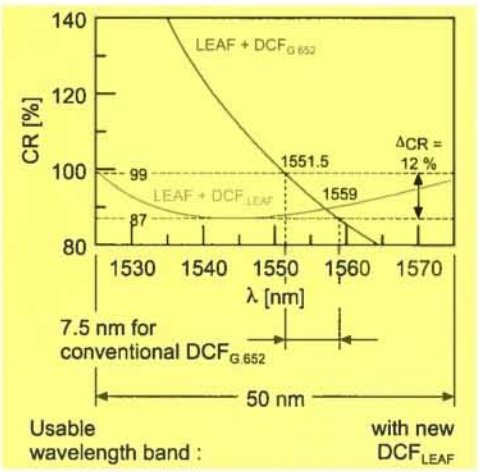

Fig. 2: Broadband slope compensation with the new DCF_{LEAF}

This means that LEAF fibre in combination with the new DCF_{LEAF} is now suitable for long-haul WDM transmission over more than the entire C Band.

[1] M. Wandel et al., "Dispersion compensating fibers for non-zero dispersion fibers", Optical Fiber Communication Conference, 2002, WU1.

[2] D. Breuer et al., "Symmetrical dispersion compensation for standard monomode fiber based communication systems with large amplifier spacing," Optics Letters, 13 (1997), pp. 982-984.

[3] N. Hanik et al., "Optimised design of transparent optical domains", Proc. European Conference on Optical Communications, 3 (2000), pp. 992-994.

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Size and Cascadability Limits of SOA-based Burst Switching Nodes

Optical Burst Switching (OBS) is a promising candidate for a more dynamic optical layer to support the next generation Internet. OBS will only be possible if fast and large switching nodes can be built. The size and cascadability of such nodes are limited by signal degradation caused by power losses, noise, and crosstalk. Our analysis shows that nodes with 16 fibres and 32 wavelengths per fibre are possible.

The optical bursts in an OBS network have typical lengths ranging from a few microseconds to several hundred microseconds, so that switching times should be less than one microsecond. Switches using semiconductor optical amplifiers (SOAs), with switching times in the nanosecond range, are well suited for this application.

To reduce signal degradation and cost we considered only single-stage node architectures. A power budget analysis shows that the "Tune-and-Select" (TAS) architecture (Fig. 1) has the potential to build large nodes. This node has *N input/output* fibres and *M wavelengths* per fibre. The incoming burst is converted into the desired output wavelength by a tunable wavelength converter and then switched to the desired output fibre by SOA gates.

To estimate the size and the cascadability of the TAS nodes for a 10 Gbit/s line rate, the bit error rate respectively Q-factor was calculated [1]. The noise generated by the optical amplifiers (SOA, EDFA) is considered and a worst case calculation is performed for crosstalk analysis. Figure 2 shows the Q-factor as a function of the number of fibres (*N*) for various numbers of wavelengths per fibre (*M*) for a single node. To leave enough margin for other impairments, a Q of 10 (BER = 10^{-22}) is taken as the limit of signal degradation. It is seen that a TAS node with 512 ports ($N = 16$ and $M = 32$) can be built.

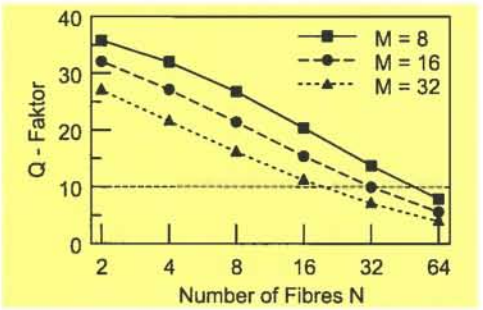

Fig. 2:
Q-factor versus number of fibres N for various numbers of wavelengths per fibre M

The cascadability of the nodes depends on the kind of wavelength converters. If 3R regenerating wavelength converters are used, the accumulation of signal degradation ceases at each converter, and many TAS nodes can be cascaded. However, the degradations accumulate if a linear converter is used, and the maximum size of TAS nodes is considerably reduced. For example, for four cascaded nodes with 32 wavelengths per fibre, we can only implement a TAS node with 4 input and output fibres if linear converters are used.

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

[1] H. Feng, E. Patzak and J. Saniter, "Size and cascadability limits of SOA based burst switching nodes", Proc. ECOC '02, Copenhagen (DK), Sept. 2002, vol. 3, 8.5.5.

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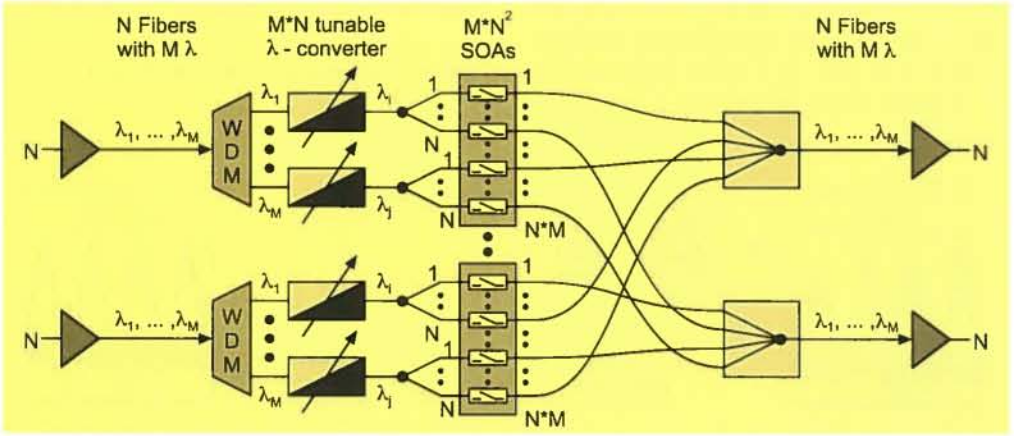

Fig. 1:
Tune-and-select (TAS) OBS switching node

Novel All-Optical 3R Regenerator with Flexible Choice of Output Wavelength

All-optical 3R signal regeneration and wavelength conversion are key functions needed in all-optical switching nodes. We developed a novel 3R architecture combining regeneration and flexible wavelength conversion. All-optical 3R regeneration at 40 Gb/s is demonstrated using compact semiconductor devices.

An all-optical 3R signal regenerator (Re-amplification, Re-timing, Re-shaping) needs clock recovery circuitry, a decision element, and circuitry for combining the clock recovery and decision functions. In the standard architecture the optical clock pulses are applied to a nonlinear decision gate that is controlled by the data signal. The data information is thus encoded onto the clock pulses. The timing and shape of the (stable) clock pulses determine the output quality. However, the clock also determines the output wavelength, and thus a matched optical clock must be fabricated for each wavelength in the ITU grid.

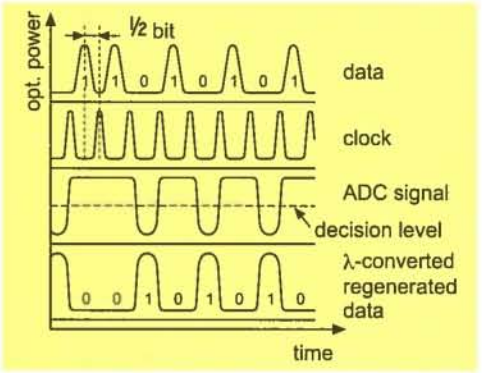

Fig. 1: Schematic of the Alternating Data Clock (ADC) 3R regenerator. Data are delayed by half a bit relative to the clock, and the combined ADC signal is converted to an arbitrary wavelength.

In our novel regenerator architecture [1] data pulses are delayed by half a bit relative to the clock pulses and combined (balanced in power) with the Alternating Data Clock (ADC) signal (Fig. 1). The ADC signal is constant during a sequence of "1" bits and it drops down during a "0" bit. The timing and shape of the resulting modulation in the ADC signal are determined by the (stable) clock pulses, not by the (possibly degraded) data signal. The ADC signal controls a wavelength-converting decision element in which the modulation signal is encoded onto a CW signal. A tunable laser or a commercially available laser in the ITU grid can be used to define the output wavelength in a flexible manner, while waveform shape and timing are determined by the clock – as needed for regeneration.

A 3R regenerator based on the ADC scheme was assembled (Fig. 2) and tested at 40 Gb/s [2]. Optical clock recovery was performed by the self-pulsating PhaseCOMB laser developed at HHI [3]. A semiconductor optical amplifier (SOA) followed by a delayed interferometer (DI) was used as the wavelength-converting decision element. A degraded 40 Gb/s PRBS signal (eye diagram at the left in Fig. 2) was injected into this regenerator. The output eye diagram is shown in Fig. 2, right. The improved quality of the output signal (both jitter and shape) can clearly be seen.

The regenerator presented here is the first 40 Gb/s true all-optical 3R regenerator using compact semiconductor devices for clock recovery as well as for decision.

[1] B. Sartorius et al., "Novel 3R regenerator architecture with wavelength flexible output", ECOC 2002, paper 6.3.3., Copenhagen (DK).

[2] C. Bornholdt et al., "Novel 3R regenerator concept demonstrated at 40 Gb/s", ECOC 2002, post-deadline paper PD 4.8, Copenhagen (DK).

[3] C. Bornholdt et al., "Self-pulsating DFB-laser for all-optical clock recovery", Electron. Lett., vol. 36, no. 4, 2000, pp. 327-328.

Bernd Sartorius (sartorius@hhi.de)

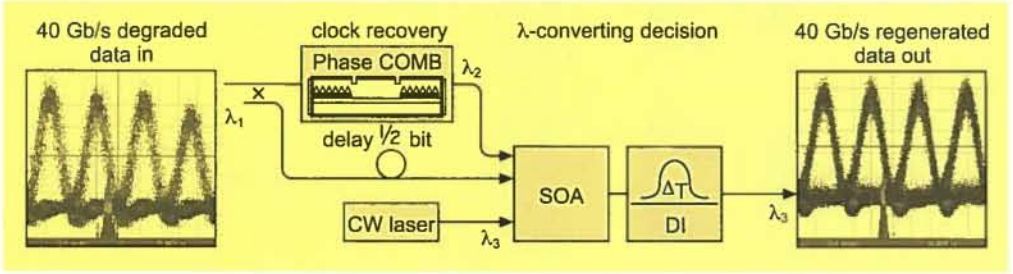

Fig. 2: Assembled 3R regenerator applying compact semiconductor devices for clock recovery and decision. Eye diagrams show degraded 40 Gb/s input signal (left) and regenerated signal at a controllable wavelength (right).

Modelling of PhaseCOMB Laser for Optical Clock Recovery

The simulation tool LDSL was applied to investigate the performance of a new operation principle for high-speed all-optical clock lasers when there are perturbations due to longitudinal spatial hole burning and residual reflections at the interfaces. Conclusions are drawn about how to suppress these perturbations.

Phase Controlled Mode Beating (PhaseCOMB) is a new operation principle for high-speed all-optical clocks. It is based on the use of three-section lasers comprising two DFB sections, detuned by about the stop bandwidth, and an integrated phase tuning section (Fig. 1). The two adjacent inner DFB modes (+1, -2) are selected for lasing by the phase tuning section. Beating of the two coupled modes leads to the wanted self-pulsation (SP) at a frequency determined by the spectral separation of the lasing modes. 3R regeneration at up to 80 GHz has been realised at HHI using PhaseCOMB lasers.

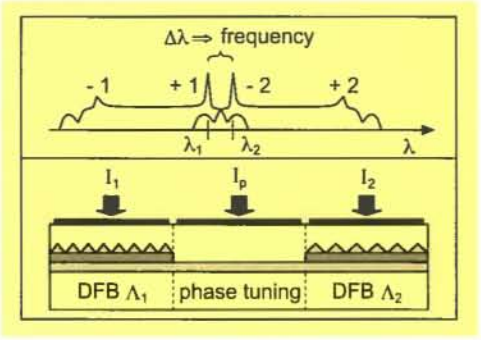

Fig. 1:
Sketch of the PhaseCOMB clock and its principle of operation

Modelling of such devices was done in cooperation with partners at Humboldt University and the Weierstrass Institute using their simulation tool LDSL [1]. When the results are compared with the measurements, two effects not considered in [1] were now found to play an important role: spatial hole burning (SHB) and residual interface reflections (RIRs).

SHB is a nonuniform carrier density due to nonuniform stimulated recombination. It is accompanied by a shift of the Bragg resonance by nearly 1 nm (Fig. 2) that perturbs the selection of the wanted modes and reduces the sizes of the parameter regions with useful self-pulsations. Nevertheless, high quality SPs from 20 GHz up to several hundred GHz can be generated by properly choosing the grating detuning as well as the DFB and phase section lengths (Fig. 3).

The impact of RIR on the self-pulsations is illustrated in Fig. 4. Depending on the phases of the RIRs relative to the those of the DFB gratings, the frequency varies over a wide

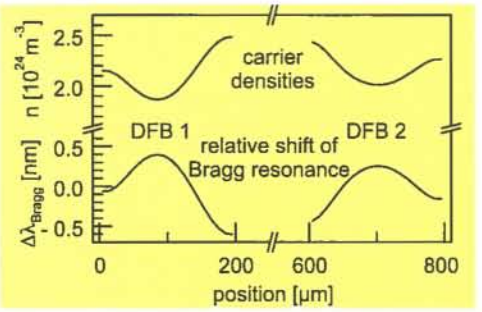

Fig. 2:
Spatial hole burning in the carrier densities and related shift of the Bragg resonance

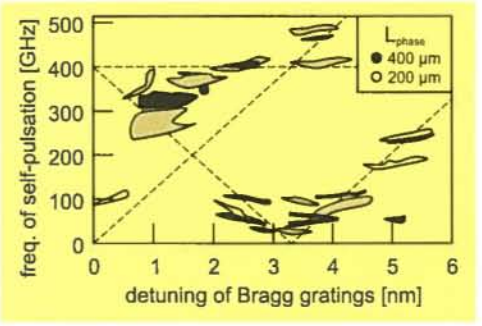

Fig. 3:
Variation of the SP frequency with the d etuning of the Bragg gratings. The vertical spread of the islands is due to phase tuning. The lines show the separations between all combinations of DFB modes.

range, and the SP may even disappear (white area). Since this phase is a random parameter, not controllable by technology, a large scatter from device to device is the consequence. By calculations we have shown that the interface reflectivity R must be less than 0.1 % to get a uniformly good performance of the devices.

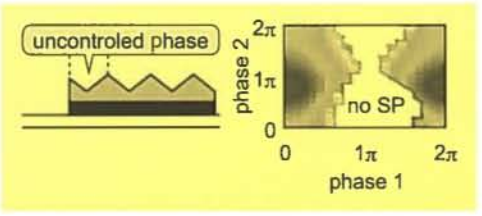

Fig. 4:
Influence of the phases of interface reflectivity R = 1 %. White: no SP. Grey scale: SP from 29 GHz (dark) to 44 GHz (pale-grey).

[1] M. Möhrle et al., "Detuned grating multi-section-RW-DFB-lasers for high speed optical signal processing", IEEE Selected Topics on Quantum Electronics, 7, 217 (2001).

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160 to 40 Gb/s Demultiplexing Using a Self-Pulsating Laser-Based Clock Recovery Device

Optical demultiplexing from 160 to 40 Gb/s is performed using a self-pulsating laser-based clock recovery device. Error-free operation is obtained, thereby demonstrating the excellent timing stability of the optical clock.

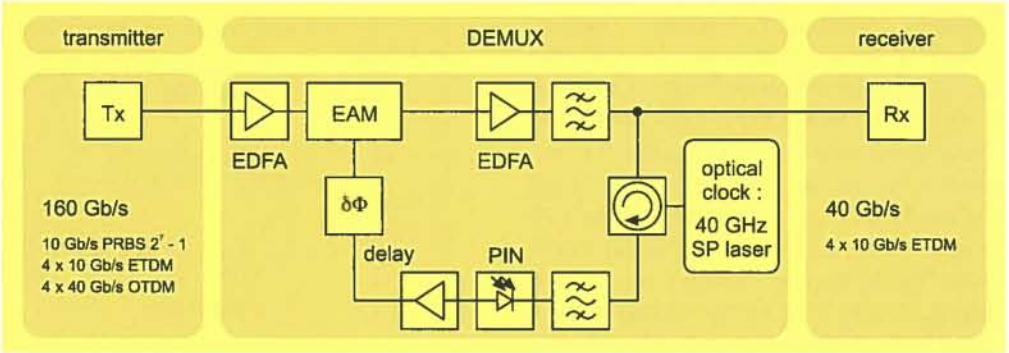

Fig. 1: Experimental setup of the 160 to 40 Gb/s DEMUX experiment

Optical demultiplexing is a key function in high speed systems that are optical time-division multiplexed (OTDM), since it enables transmission at bit rates beyond the speed of electronic signal processing. Moreover a cost reduction can be obtained by avoiding opto-electronic conversion at high data rates. The devices needed in the DEMUX are an optical gate and a clock recovery unit. The clock recovery device operates at the base rate of the OTDM systems and triggers the gate to select particular channels for detection. However, the switching window must have a timing precision matched to the line rate. Since the relative spacing between the adjacent OTDM channels decreases with increasing channel number, the timing stability must match the demands of the line rate.

Presently 160 Gb/s OTDM systems with 40 Gb/s base rates are under investigation. We therefore evaluate the application of a novel 40 GHz self-pulsating laser for all-optical clock recovery [1] in a 160 to 40 Gb/s DEMUX experiment.

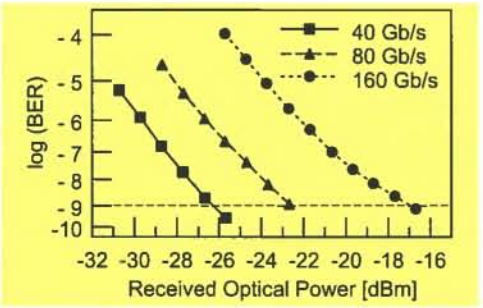

Fig. 2: System performance of the DEMUX receiver for demultiplexing 40, 80 and 160 Gb/s signals to a 40 Gb/s signal

The experimental setup is shown in Figure 1. This can be regarded as general 160 Gb/s testbed for the all-optical clock recovery module. A 160 Gb/s OTDM signal, based on 4 x 40 Gb/s electrical time-division multiplexed (ETDM) channels, is launched into the DEMUX using an electrically driven electro-absorption modulator (EAM) acting as an optical gate [2]. The demultiplexed 40 Gb/s signal at the output of the EAM is amplified and divided into two streams. One stream is used for signal detection in a 40 Gb/s ETDM receiver, and the other is injected into the self-pulsating laser. The 40 GHz optical clock pulses from the device are converted to an electrical signal which drives the EAM.

The ETDM receiver was used to characterize the DEMUX performance by BER measurements on the demultiplexed 40, 80 and 160 Gb/s signals. The results are summarized in Fig. 2. The BER curves demonstrate error-free demultiplexing down to a BER of less then 10^{-9}. The system penalties are only 0.7 dB for 80 Gb/s and 2.7 dB for 160 Gb/s, allowing for the 3 dB drop in sensitivity when the bit rate is doubled.

In conclusion, 160:40 Gb/s optical demultiplexing with an all-optical clock recovery device was demonstrated. The timing stability of the synchronized 40 GHz self-pulsating laser has a jitter matched to the operational demands at 160 Gb/s. This DEMUX could be upgraded to an all-optical solution in future if an optically driven gate, such as an interferometer-based structure, were to be used.

[1] S. Bauer et al., Electron. Lett., vol. 38, pp. 334-335, 2002.

[2] E. Lach et al., Proc. OFC 2002, TuA2, 2002, Anaheim, USA.

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Active Feedback Laser for Clock Recovery

We present the active feedback laser (AFL) as a new device concept for tunable high frequency pulse generation. The simple design allows for cost-effective fabrication. Its performance is demonstrated to be comparable to that of other solutions for all-optical clock recovery.

A key functionality for future all-optical networks will be optical pulse sources, which are required for several applications in signal processing. Particularly interesting are applications where the pulses are synchronised by optical data injection. This clock functionality can be used for example for the control of add-drop multiplexers in OTDM systems. The generation of pulses using integrated optics offers many advantages. Besides overcoming the speed limitations of their electronic counterparts, there are the benefits of low power consumption, low cost and high reliability.

There are now several competing methods for high speed pulse generation, including mode-locked lasers (MLLs) and PhaseCOMB lasers using two coupled DFB lasers giving a beating pulsation. Both designs suffer from the complex technology needed. In the case of the MLL the pulsation frequency is defined by the internal roundtrip time, so that the device length must be controlled very precisely, whereas the PhaseCOMB laser relies on the detuning of DFB gratings, which requires additional technological steps.

The new approach presented here is a delayed feedback setup using a single-mode laser. It can be used for the generation of pulsations in which the frequency scales with the feedback level. The innovation in the AFL is the integration of an active feedback cavity (AFC) in a DFB laser, comprising both phase and amplifier sections. This overcomes the inherent losses of passive solutions. The large amount of feedback due to the internal amplifier results in pulse frequencies up to the limit given by the roundtrip time in the AFC. Details are given in [1].

A device realised for 40 GHz self-pulsation is shown in Fig. 1. It is designed as an index-coupled bulk hetero-structure ridge-waveguide laser comprising a 200 µm DFB section, a 350 µm passive phase tuning section and a 250 µm active section. The DFB facet is anti-reflection coated and an uncoated end facet acts as a mirror.

The device delivers an output power of 1 mW into the fibre and has a large frequency tuning range of 20 GHz, which can be controlled by simply adjusting the amplifier and phase currents. The performance of the device remains constant over the whole tuning range. Typical data are an extinction ratio of 10 dB and a phase noise equivalent jitter of 300 fs when locked to an injected data signal. Figure 2 shows pulse traces for a 40 Gb/s data signal and the recovered clock signal.

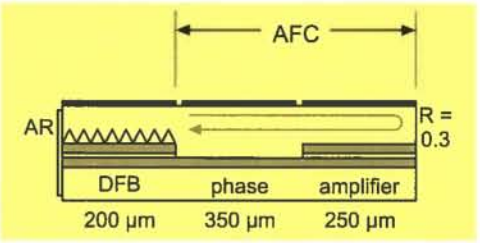

Fig. 1:
Schematic of active feedback laser for 40 GHz self pulsation

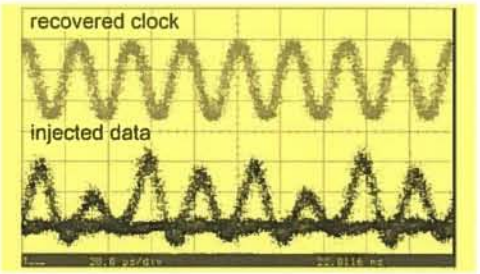

Fig. 2:
Pulse traces of the recovered clock and the injected data signal at 40 Gb/s

In summary the active feedback laser is a cost-effective pulse source that meets the demands of future optical networks.

The results have been obtained under the framework of the Research Partner Program of Alcatel.

[1] S. Bauer, O. Brox, J. Kreissl, G. Sahin and B. Sartorius, "Optical microwave source", Electron. Lett., vol. 38, pp. 334-335, 2002.

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320 Gb/s Optical Sampling

A semiconductor-based all-optical sampling system to display a 320 Gb/s optical eye diagram is demonstrated for the first time. The system uses a gain-transparent ultrafast nonlinear interferometer (GT-UNI) as the sampling gate.

In future high-speed TDM systems (160 Gb/s and above), optical sampling for in-service quality monitoring at the full line rate will be vital. We demonstrate a semiconductor-based sampling system that allows the measurement of 320 Gb/s eye diagrams [1]. The sampling gate is a GT-UNI, which uses the gain-transparent (GT) principle in which the optical control pulses are in the spectral gain region of an SOA and cause a change of the refractive index at a signal wavelength in the transparency region (i.e. below the bandgap) of the SOA. This leads to excellent input-to-output linearity and wide wavelength tunability of the input signal, which are both advantageous for optical sampling.

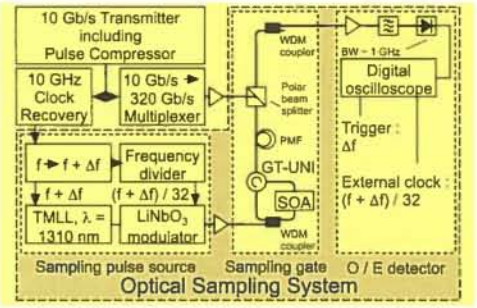

Fig. 1: Experimental setup

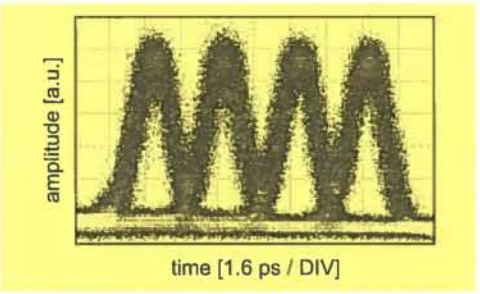

Fig. 2: Optical eye diagram of a 320 Gb/s data signal (4 channels turned on)

Figure 1 shows schematically the experimental setup. A 320 Gb/s data signal was generated by multiplexing the signal of a 10 Gb/s PRBS RZ transmitter (1550 nm, 650 fs $sech^2$ pulses, 0.2 ps rms timing jitter). Part of the 10 Gb/s signal was used for RF clock line extraction. The sampling system comprised three main parts: the sampling pulse source, the GT-UNI sampling gate and the opto-electrical (O/E) detector. For the sampling pulse source we used a semiconductor modelocked laser (TMLL) at 1300 nm (1.5 ps $sech^2$ pulses, 0.2 ps rms timing jitter), driven by the 10 GHz extracted clock signal shifted by Δf = 50 kHz. Due to the limited clock speed of the digital oscilloscope in the O/E detector, the sampling pulse rate was reduced to 310 MHz by a $LiNbO_3$ Mach-Zehnder modulator. The sampling pulses opened a short gating window in the GT-UNI and the incoming data signal was gated to the output port (the optical sample). The gating window width of 1.8 ps was determined by a piece of polarization-maintaining fibre (PMF) in the GT-UNI, with a length of 1.2 m. Finally, the peak powers of the optical samples were detected using a photodiode (1 GHz bandwidth) and displayed on a digital oscilloscope, which was triggered by the frequency offset Δf.

Figure 2 shows the measured optical eye diagram of a 320 Gb/s data signal. The average powers of the data signal and sampling pulses at the input of the GT-UNI sampling gate were +23 dBm and -4 dBm, respectively.

The eyes have a clear opening and the same shapes at a persistence of 120 traces. From the eye diagrams, we obtain a FWHM of the eyes of about 2.0 ps, which corresponds to an optical bandwidth of the sampling system of about 250 GHz. This is in good agreement with the gating window width of the GT-UNI, which we measured earlier. Jitter of about 650 fs can be estimated from a horizontal histogram of the flanks of the eyes.

[1] C. Schmidt, C. Schubert, S. Watanabe, F. Futami, R. Ludwig and H.G. Weber, "320 Gb/s all-optical eye diagram sampling using gain-transparent ultrafast-nonlinear interferometer (GT-UNI)", Proc. ECOC '02, Copenhagen (DK), Sep. 2002, paper 2.1.3.

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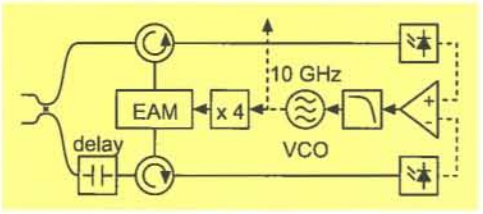
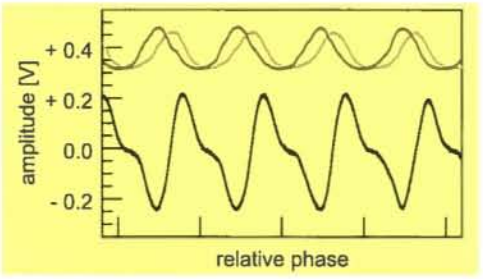
160 Gb/s Optical Clock Recovery using an Electro-Absorption Modulator

A 10 GHz clock recovery device for a 160 Gb/s RZ data signal is demonstrated using a bi-directionally operated electro-absorption modulator (EAM) as phase comparator. It employs a differential detection scheme and achieves excellent locking stability.

Clock recovery is an essential operation in devices such as receivers, regenerators, add-drop multiplexers and in-field optical sampling systems. We report on innovations for 160 Gb/s clock recovery using the electro-optical PLL described in [1]. The innovations are the use of an EAM as a phase comparator and a differential scheme in which the EAM is operated with two counter-propagating data signals. The locking stability is improved by this differential scheme.



The clock recovery setup is shown in Fig. 1. The 160 Gb/s optical data signal (single polarization) is split into two branches and passed through the EAM using two circulators. After electro-optical conversion the two signals are recombined to drive the 10 GHz voltage-controlled oscillator (VCO). The VCO signal is finally multiplied to 40 GHz and fed into the electrical input of the EAM to close the loop of the PLL.



In this setup the EAM acts as an ultra-fast electro-optical phase comparator. The optical powers transmitted through the EAM to both sides are determined by the relative phase between the data signal and the 40 GHz RF signal driving the EAM. Figure 2 (upper traces) shows these two signals as a function of the relative phase. The two signals are phase-shifted because of the optical delay in one branch at the EAM input. The difference between these two electrical signals results in a bipolar feedback signal (Fig 2, lower trace) for the VCO, which is, within the locking-range, proportional to the relative phase.

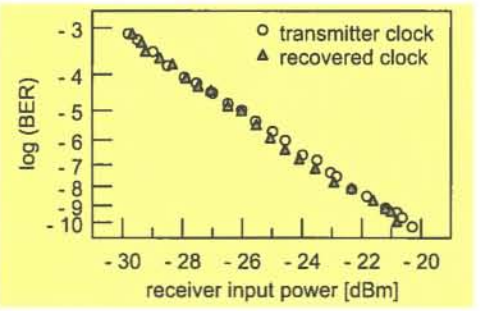


Fig. 3:
Bit-error rates for demultiplexing from 160 Gb/s to 10 Gb/s using the clock of the 10 Gb/s transmitter (open circles) and the recovered clock (grey triangles)

Fig. 1:
Schematic of the clock recovery setup

The results of a 160 Gb/s to 10 Gb/s demultiplexing experiment are shown in Fig. 3. The bit-error rates (BERs) shown as open circles were measured with the electrical transmitter clock driving the demultiplexer, while the grey triangles are the measurements using the recovered clock. It can be seen that the BER performance of the demultiplexer was the same in both cases. Hence no penalty is incurred due to the clock recovery operation.

The design of this clock recovery device is independent of the polarization. Furthermore it has the potential for hybrid planar light wave circuit integration if the circulators are replaced by 3 dB couplers.

Fig. 2:
Transmitted output powers of the EAM in both directions (upper traces) at 40 Gb/s. Subtraction yields a bipolar VCO feedback signal (lower trace).

[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 Gbit/s data signals using phase-locked loop with interferometric optical switch based on semiconductor optical amplifier", Electron. Lett., vol. 37, no. 8, 2001, pp. 509-510.

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Self-Cascaded Electro-Absorption Modulator for Improved Switching Performance

The self cascading of an electro-absorption modulator (SCEAM) using commercially available components improves the switching performance of a single electro-absorption modulator.

Semiconductor-based electro-absorption modulators (EAMs) are very attractive as versatile optical components in high-speed optical communication systems. They can be used for operations such as pulse generation, clock recovery and demultiplexing. Their advantages are compactness, polarization insensitivity and integrability with other components. The disadvantage of EAMs is their limited operation speed, which depends on the electrical bandwidth. Usually two cascaded EAMs are used to overcome the bandwidth limitation and to reduce the switching time.

The Self-Cascaded Electro-Absorption Modulator (SCEAM) significantly improves the switching performance of a commercially available EAM by using it in a bidirectional mode. In a SCEAM the light signal passes through the same EAM twice, once in each direction. As a result the switching window is shortened and the extinction ratio is increased.

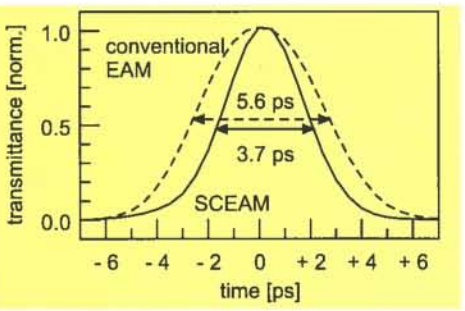

Fig. 2: Switching windows of a SCEAM and a conventional EAM

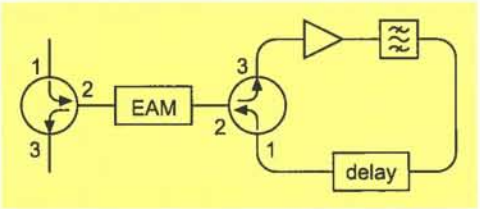

Fig. 1: Setup of the Self Cascaded Electro-Absorption Modulator (SCEAM)

The SCEAM consists of an optical three-port circulator, an EAM and an optical feedback loop (Fig. 1). The input light passes via the circulator through the EAM, where it is switched for the first time. In the circulator feedback loop the signal is amplified and filtered before it passes through the EAM in the opposite direction, where it is switched for the second time. The optical delay line is used to synchronize the second pass to the first pass.

Double switching of the same signal results in a larger extinction ratio and a shorter switching window. Appropriate detuning of the loop delay shortens the width of the switching window even further, but at the expense of a reduction of the extinction ratio and an increased insertion loss. Since the SCEAM is insensitive to polarization and the adjustment of the delay is not critical, the setup is robust to changes of the environment and operation conditions. All components necessary to set up a SCEAM are standard optical components.

Switching window measurements at 40 GHz are shown in Figure 2 with a relative loop delay = 3 ps. The window with the SCEAM (width 3.7 ps, extinction ratio 21 dB) is a third shorter than for a single EAM (5.6 ps, 19 dB).

When used as an optical time division multiplexing (OTDM) demultiplexer from 160 Gbit/s to 40 Gbit/s, the SCEAM has a 50 % better temporal detuning range of the data pulses than a conventional EAM. This is because its shorter switching window and higher extinction ratio give better suppression of the neighbouring channels.

Pulse widths of less than 3 ps were achieved when using a SCEAM to generate short optical pulses from a cw signal.

This work is supported by the German Research Fund (DFG) under grant WE 1726/4-2.

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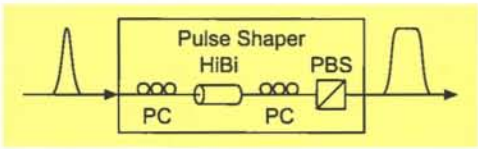
Pulse Shaping for a 160 Gbit/s 3R Wavelength Converter

A 160 Gbit/s all-optical wavelength converter with 3R regenerating capability is demonstrated for the first time. It comprises a simple pulse shaper to form almost rectangular gating pulses and suppress the phase-to-amplitude noise conversion. This pulse shaper can generally be used to reduce the liability to phase noise in fibre-based all-optical gates, even at bit rates above 160 Gbit/s.

Wavelength conversion and 3R regeneration (Re-amplification, Re-shaping, Re-timing) will be key functions in future all-optical networks. Wavelength converters using all-optical switches as decision gates can combine both functions. A fast decision gate is required to realize 3R wavelength conversion at 160 Gbit/s and higher speeds. Phase noise in the data pulses at the inputs of such fast gates is generally transformed to amplitude noise in the output pulses, which degrades the regenerator performance.

A pulse shaper to suppress phase-to-amplitude noise conversion is incorporated in the first 3R wavelength converter to be demonstrated at 160 Gbit/s, to our knowledge [1]. It uses ultra-fast switching in a highly nonlinear optical fibre. The setup of the pulse shaper is shown in Fig. 1.



An incoming pulse is coupled into a highly birefringent fibre (HiBi fibre, length 0.5 m, differential group delay 0.85 ps) and recombined in a polarization beam splitter (PBS). An output pulse with a flattened top shape (full width at half maximum (FWHM) 2.9 ps) is obtained by adjusting the input polarization and the length of the HiBi fibre. An automatic polarization controller can be used at the input of the pulse shaper to achieve polarization-independent operation.

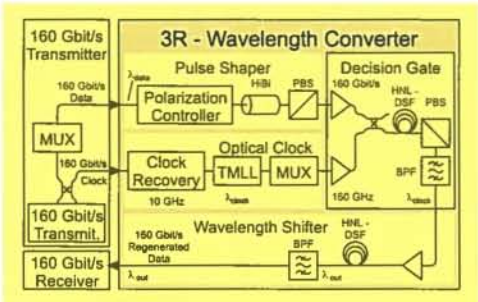


Figure 2 shows the experimental setup of the 3R regenerating wavelength converter. The 160 GHz optical clock is generated by multiplexing the signal of a 10 GHz tunable mode-locked laser (TMLL, $\lambda = 1537$ nm, 1.8 ps sech^2 pulses). The decision gate was an optical Kerr switch consisting of 1.6 km of Highly Nonlinear Dispersion-Shifted Fibre (HNL-DSF), $\gamma = 20\ W^{-1}\ km^{-1}$, $\lambda_0 = 1552.5$ nm).

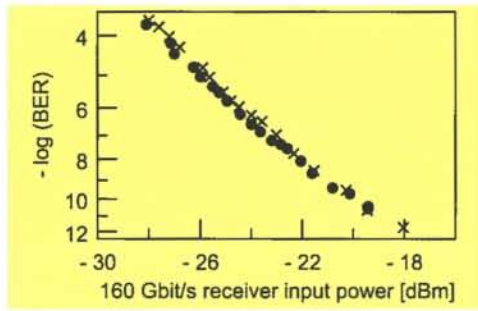


Fig. 3:
BER performance for a 3R wavelength-converted 160 Gbit/s signal (dots), compared to that of a 160 Gbit/s back-to-back measurement (crosses)

The output pulses of the pulse shaper were input into the decision gate as control pulses to switch clock pulses by cross phase modulation (XPM) -induced polarization rotation. The wavelength shifter, based on supercontinuum (SC) generation in HNL-DSF (length of 850 m, $\lambda_0 = 1550.3$ nm), was used for arbitrary wavelength allocation of the 3R wavelength-converted signal.

Fig. 1:
Schematic of the pulse shaper

The performance of the 3R regenerating wavelength converter is shown in Fig. 3. Error-free operation for 160 Gbit/s 3R wavelength conversion from $\lambda = 1554$ to 1541 nm was obtained, without significant penalty compared to a 160 Gbit/s back-to-back measurement.

[1] C. Schubert et al., "Improved performance of a 160 Gb/s all-optical switch using rectangular gating pulses", Proc. ECOC '02, Copenhagen (DK), Sep. 2002, paper 8.3.7.

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Fig. 2:
Experimental setup for 3R wavelength conversion

Optical Intensity Filter for Noise Squeezing and Pulse Shaping

A new design of a highly asymmetric nonlinear optical loop mirror for the regeneration of OTDM signals is proposed. It features all-optical noise suppression and pulse reshaping.

In optical fibre transmission systems, signal regeneration is needed to combat the transmission impairments associated with waveform distortion due to dispersion, fibre nonlinearity and noise. Intensity-dependent threshold devices, such nonlinear optical loop mirrors (NOLMs), can be applied for noise reduction. A NOLM was operated successfully as an intensity filter in a transmission experiment using RZ pulses of picosecond width. After regeneration by the NOLM the pulses could be transmitted over 160 km of standard single mode fibre (SMF) [1].

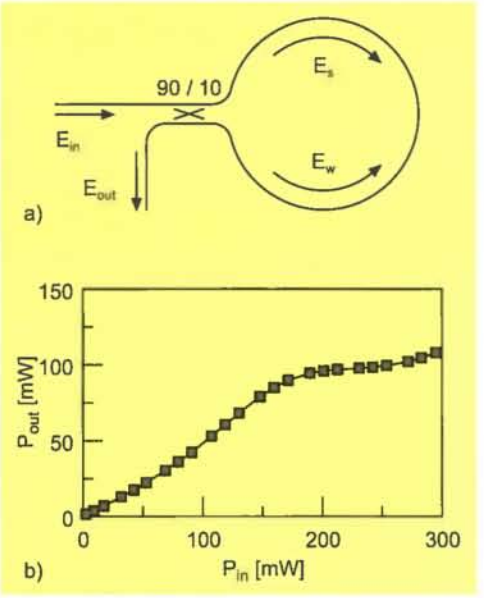

Fig. 1: a) Schematic of a NOLM. b) Measured transfer function.

A schematic of a nonlinear intensity filter is shown in Fig. 1a. The incoming signal is amplified to a power level close to that of the fundamental soliton and is then split by a 90/10 NOLM input coupler into strong and weak components ES and EW, respectively. These components in the right and left circulating paths have different nonlinear phase shifts. The combination of both paths at the NOLM output results in intensity-dependent interference. As shown in Fig. 1b, the measured transfer characteristics of a NOLM with a SMF has a plateau at input powers close to the soliton power. Due to this plateau, amplitude fluctuations (e.g. noise) of the incoming signals are reduced at the NOLM output.

In the new NOLM design, we want to reshape the pulses as well as reduce the noise [2]. To investigate pulse shaping we first calculate the nonlinear pulse propagation on the SMF. The calculated widths of $sech^2$-pulses travelling along the fibre are shown in Fig. 2. The input widths are 2.3, 2.9 and 3.5 ps, respectively, corresponding to ±20 % deviation from the mean width. For an average power of 1 dB above the power of the fundamental soliton the pulses are compressed due to fibre nonlinearity. We see from Fig. 2 that pulses with larger widths are compressed much more than the narrow pulses. In fact, at L = 0.7 km the variation of the pulse widths is minimum.

We utilize this pulse shaping effect to produce an improved intensity filter by choosing a NOLM with a fibre length of 0.7 km and input power of 1 dB above the soliton power. This NOLM intensity filter achieves both noise reduction and pulse shaping, as shown by the calculated eye diagrams at the NOLM input and output in the inset of Fig. 2.

This work was supported by the European Commission as part of the IST project TOPRATE.

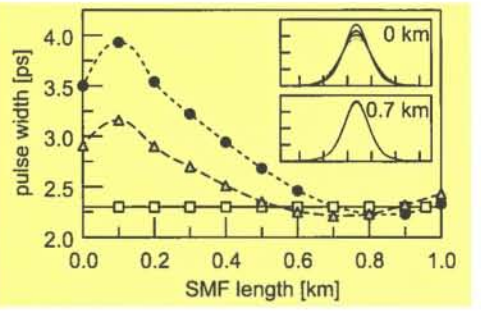

Fig. 2: Nonlinear decrease of pulse width for 2.3, 2.9 and 3.5 ps input widths

[1] R. Ludwig, A. Sizmann, U, Feiste, C. Schubert, M. Kroh, C. M. Weinert and H. G. Weber, "Experimental verification of noise squeezing by an optical intensity filter for high-speed transmission", ECOC'01, Amsterdam (NL), Paper Tu.B. 2.7.2001.

[2] C.M. Weinert, "Optical intensity filter for noise squeezing and pulse shaping", Proc. OFC'02, Anaheim (CA, USA), paper ThGG48W, 2002.

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Monolithic Mode-Locked Lasers for 160 Gb/s TDM Applications

First mode-locked laser OEICs on GaInAsP/InP for 160 Gb/s hybrid mode locking applications are demonstrated. They feature 40 GHz repetition rate, 2.4 ± 0.2 ps pulse lengths, 220 ± 30 fs timing jitter, and more than 0 dBm fibre coupled power.

The implementation and up-grading of flexible and high capacity optical communication networks is expected to be realized in the long term by the use TDM and WDM system technologies. In particular, stable, compact and optimised high speed transmitters, available at low cost, are important building blocks for the application of TDM transmission and signal processing techniques. The availability of high performance monolithically integrated components is an important issue, especially for transmission rates beyond 40 Gb/s.

Monolithic mode-locked laser OEICs on GaInAsP/InP have been fabricated using the HHI integration process [1] and have been characterized for passive and hybrid mode-locked operation at 40 GHz. The repetition frequency and emission wavelength can both be finely tuned.

For hybrid mode locking, low timing jitter (220 ± 30 fs), large range of repetition rate (500 MHz) and minimum pulse widths of 2.4 ± 0.2 ps have been simultaneously observed by changing only the gain current and the absorber voltage [2]. The pulses are nearly transform limited, and fibre-coupled output powers exceeding 0 dBm have been obtained. Additional frequency shifts are possible by electrical and thermal refractive index changes due to carrier injections into integrated phase and heater sections.

The demonstrated device performance data represent an important step towards the economic production of monolithically integrated 40 GHz pulse sources for 160 Gb/s systems.

The work was supported by the Federal Ministry of Education and Research under grant 01 BP 070.

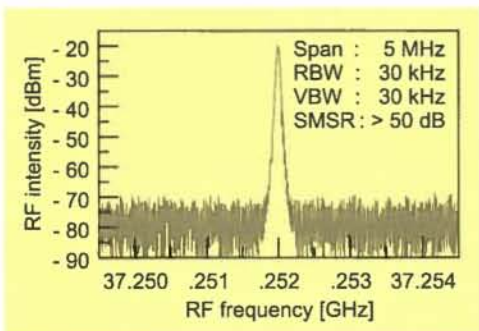

Fig. 4:
RF spectrum around subcarrier frequency for hybrid mode locking at room temperature

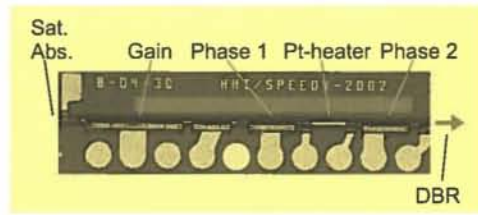

Fig. 1:
Photograph of a monolithic mode-locked laser (top view)

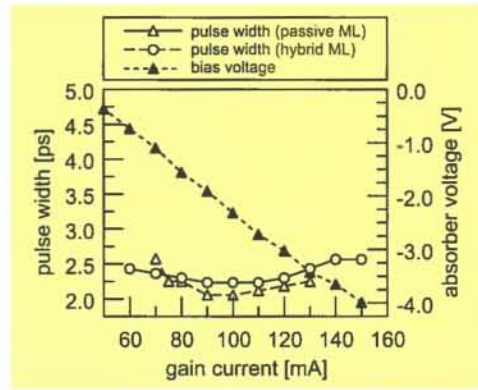

Fig. 2:
Minimum pulse widths and required absorber voltages for passive and hybrid mode locking at room temperature (phase and Distributed Bragg Reflector(DBR) sections not biased; ML: mode locking)

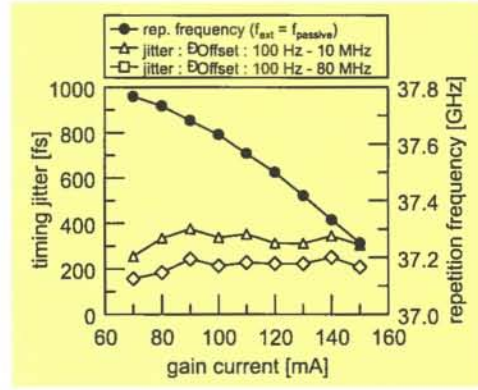

Fig. 3:
Timing jitter and repetition frequency as functions of gain current for hybrid mode locking at room temperature (biased for minimum pulse width; phase and DBR sections not biased)

[1] R. Kaiser and H. Heidrich, "Optoelectronic/photonic integrated circuits on InP between technological feasibility and commercial success", IEICE Transactions on Electronics, vol. E85-C, no. 4, pp. 970-981, 2002.

[2] R. Kaiser, B. Hüttl, H. Heidrich, S. Fidorra, W. Rehbein, H. Stolpe, R. Stenzel, F. Boczianowski, G. Jacumeit and M. Kroh, "Tunable mode-locked lasers on GaInAsP/InP with 2 ps pulses and low timing jitter", Internat. Semiconductor Laser Conf. (ISLC) 2002, post-deadline paper #PD2, Garmisch-Partenkirchen (D), 2002.

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Multifunctional Optical Amplifying Microring Resonators for Integration in Photonic ICs

Monolithically integrated active ring resonators may become a viable approach for optical signal processing at rates up to a few tens of gigabits per second for WDM applications (e.g. filtering, Optical Add-Drop-Multiplexer (OADM), wavelength conversion) and for TDM switching. Evaluation of their potential and limits is a main issue.

Monolithically integrated microring devices with optical amplification (OA) take advantage of resonant power enhancement. The signals propagate nearly independently clockwise and/or counter-clockwise around the rings. Coupled rings can generate novel filter functionalities with controlled filter responses. Since the filter quality and resonance enhancement are very sensitive to the resonator losses, integrated OAs in each ring are indispensable for high performance cascaded ring structures.

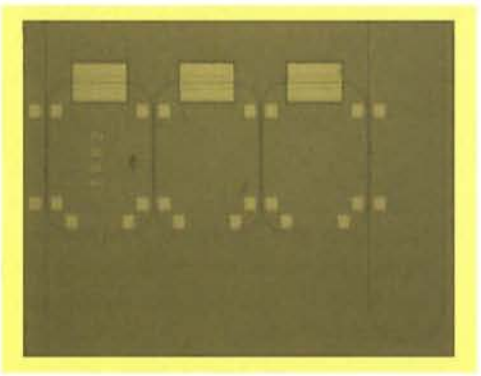

Fig. 1: Micrograph of a triple ring resonator with integrated OA sections and heaters to trim the separate rings

First OA integrated OADM and flat-top filter devices have been fabricated with a 50/100 GHz free spectral range (Fig. 1) [1]. All-active devices could be demonstrated, including single mode emitters, WDM interleavers and dispersion compensating filters (Fig. 2) [2]. Furthermore, first cw experiments on non-degenerate four-wave mixing indicate a high wavelength conversion efficiency (Fig. 3).

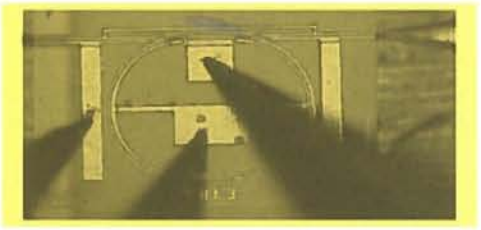

Fig. 2: Micrograph of an all-active ring resonator device with contacted feeding, coupler, and ring sections

This work was supported by the DFG under grant HE 3366/2-1 and by the Federal Ministry of Education and Research of Germany under grant 01 BC 925.

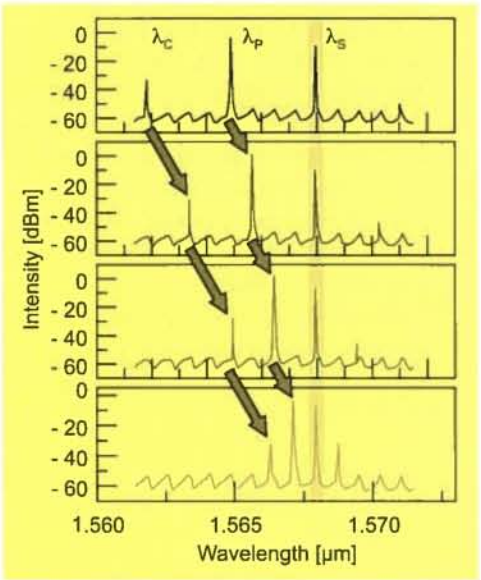

Fig. 3: All-optical channel switching experiment. The signal wavelength λ_S was kept fixed while the pump wavelength λ_P was varied in multiples of the Free Spectral Range (FSR) of the ring resonator. The shaded areas indicate the converted wave.

[1] D.G. Rabus, M. Hamacher, H. Heidrich and U. Troppenz, "Box-like filter response of triple ring resonators with integrated SOA sections based on GaInAsP/InP", Proc. 14th Indium Phosphide and Related Materials Conf. (IPRM '2002), pp. 479-482.

[2] U. Troppenz, M. Hamacher, H. Heidrich and D.G. Rabus: "All-active GaInAsP/InP ring for widespread functionalities in the wavelength domain", Proc. 14th Indium Phosphide and Related Materials Conf. (IPRM '2002), pp. 475-478.

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All-Active Tapered 1.55 µm Index-Coupled InGaAsP BH-DFB Lasers With Continuously Chirped Grating

All-active tapered 1.55 µm index-coupled InGaAsP BH-DFB lasers incorporating a continuously chirped grating have been realized for the first time. The lasers have large optical output powers, small far fields and high single mode yield.

The implementation of low-cost transmitter modules for fibre-optic applications requires efficient coupling of the light from the laser light source into a single mode fibre. This can be achieved by incorporating a spot-size converter into the laser that basically relies on a tapered waveguide structure. We have previously developed such lasers as Fabry-Perot devices employing the concept of a tapered active stripe in conjunction with a buried heterostructure (BH) design [1]. This concept offers the advantage, amongst others, of realizing tapered lasers with relatively short cavities (< 500 µm), thus allowing a large number of devices to be accommodated on a wafer.

In the present work we have successfully extended this approach to DFB-type lasers. This is difficult because, due to the tapered design of the active stripe, the index of refraction determining the Bragg wavelength for a given DFB grating varies along the laser cavity (Fig. 1). Hence, in order to achieve single mode behaviour the Bragg grating period must be chirped according to this variation (Fig. 2). As a result, the grating period decreases from the front of the taper (low n_{eff}) to the back of the taper (high n_{eff}), with pitch variations of the order of only 10^{-3} nm.

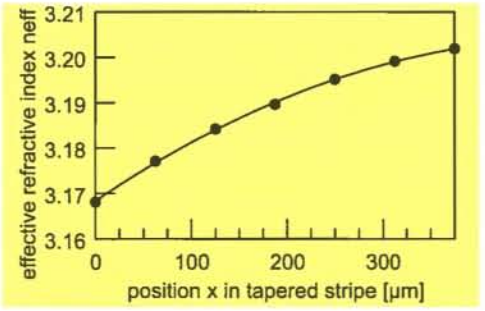

Fig. 1:
Calculated effective refractive index neff as a function of the position x in the tapered stripe

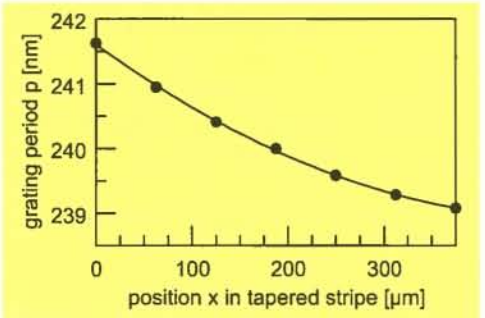

Fig. 2:
Optimized distribution of grating period along the tapered stripe

To accomplish such extremely demanding chirped gratings we applied a novel electron beam lithography method developed recently in our group [2]. Instead of using the conventional beam addressing scheme, which is generally limited to a resolution of a few nanometers, additional correctional elements for beam deflection in the e-beam system have been used as a repeatedly moved vernier. In this way it is possible to generate almost any grating period that can be expressed analytically.

Figure 3 shows the optical output power of upside-up mounted lasers, the front facets of which are AR-coated while the back facets are left as-cleaved. More than 60 mW of CW output power has been achieved. This value is equivalent to the optical output power of comparable lasers with a straight active stripe. The measured side-mode suppression ratio (SMSR) was more than 50 dB at 100 mA. The far-field angles (FWHM) are 14° in the lateral and 20° in the vertical direction. Compared to non-tapered DFB lasers of the same heterostructure design, these values mean a reduction of more than 12° in both directions. Lasers from different laser-bars indicate a single mode yield of more than 70 %, which is distinctly higher than commonly achieved with straight DFB lasers of otherwise the same design.

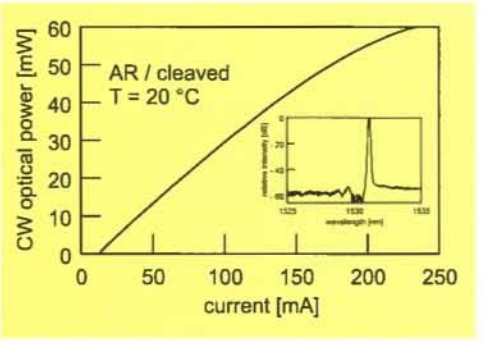

Fig. 3:
Output power and spectrum of tapered DFB-BH laser

[1] M. Möhrle et al., Proc. 14th IPRM 2002, Stockholm, Sweden, pp. 27-30.

[2] R. Steingrüber et al., Microelectronic Engineering, vol. 61-62, pp. 331-335, 2002.

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Development of a Broadband InP-Based Mach-Zehnder Modulator with Electro-Optical Bandwidth Greater Than 40 GHz

An InP-based Mach-Zehnder-modulator with an optical-mode transformer and an electro-optical bandwidth above 40 GHz has been developed. The fabrication process is designed to achieve good reproducibility and high yield. Current research activities are directed towards higher bitrates of 80 – 160 Gbit/s. A hybrid integration of a driver IC into a modulator module is also under development.

Despite the present downturn in the telecommunication industry, there is an increasing demand for fast external modulators for 40 Gbit/s NRZ and RZ formats. There is also an increasing interest in new modulation formats such as carrier-suppressed RZ (CS-RZ) or differential phase shift keying (DPSK). Indium phosphide (InP) modulators based on a Mach-Zehnder interferometer (MZI) structure with a travelling wave electrode (TWE) design can deliver 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 for the modulator, its structure is much smaller (< 3 mm^2) and needs less driving voltage ($V_{pp} \approx 2V$) than comparable devices made with GaAs or lithium niobate. This inherently low driving voltage is one of its key assets at future transmission rates of 80 Gbit/s and above.

Once developed, modulation formats other than RZ and NRZ, such as CS-RZ or DPSK, can be handled with little structural changes.

The schematic layout of the modulator is shown in Fig. 1. The two TWE electrodes are designed as coplanar waveguides. Their overall impedance can be matched to 50 Ω by the capacitive load of the distributed electrodes in the MZ arms.

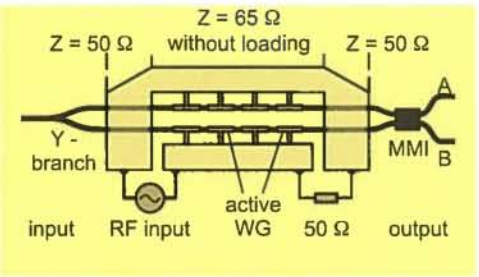

Fig. 1: Schematic layout of an MZI-based modulator with capacitively loaded travelling wave electrodes

The cross-section of an MZI sector is shown in Fig. 2. The layers with the various material sequences are shown schematically.

The electro-optical response of this device can be seen in Fig. 3. An electro-optical bandwidth of 42 GHz has been achieved with this design at a period length of

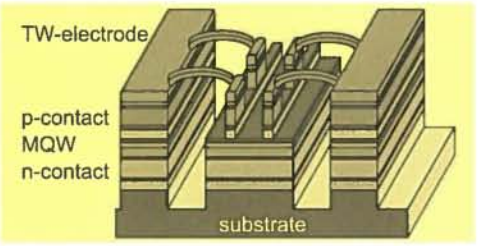

Fig. 2: Perspective view of an MZI sector with capacitively loaded TWEs via air-bridge contacts

500 µm for the capacitive loads, but further improvements up to modulation speeds of 160 Gbit/s should be possible with this approach.

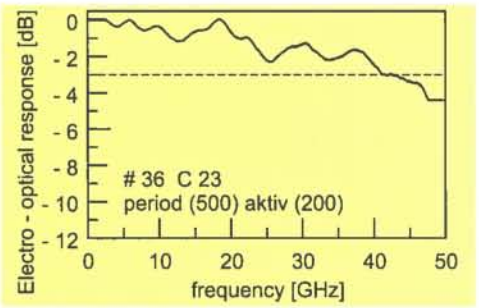

Fig. 3: Electro-optical response measured by a fast photodiode

The optical design of this modulator includes an optical-mode transformer for coupling to cleaved fibres with low insertion loss. The incorporation of this etched spot size converter in the manufacturing process and the selective chemical etching of the platinum in the metal top contact have been the key achievements in this successful development.

Current developments include a hybrid integration of the modulator together with the driver electronics. Further improvements for transmission rates up to 80 – 160 Gbit/s are expected if the modulator and the dedicated electronics for hybrid integration are realized together.

This work was supported by the Federal Ministry of Education and Research under grants 01 AK 936B and 01 BP 273.

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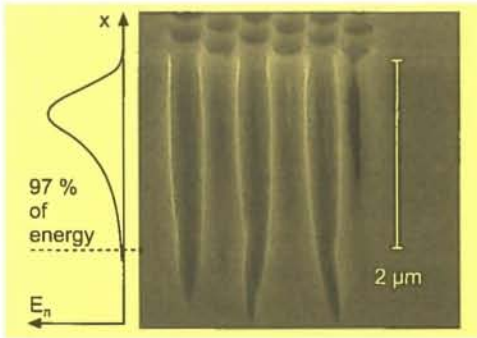
Nanotechnology for the Fabrication of Planar InGaAsP/InP Photonic Crystal Devices

The use of planar Photonic Crystal (PhC) ICs is one of the most promising approaches for miniaturizing monolithically integrated photonic devices. The focus of this work is on obtaining frequency dispersion in the bulk of such PhCs. A very demanding fabrication process is required.

Future cost-efficient WDM devices based on planar photonic crystals would combine high density integration (sharp bends, splitters, etc.) with novel active functionality (tunable dispersion, enhancement of nonlinearity, etc.). However, the major challenges are to achieve low propagation losses due to off-plane scattering at imperfections and low coupling losses due to Fresnel reflections at interfaces.

To tackle the scattering problem a reliable etching process for extremely large aspect ratios is needed. Therefore a two-step etching process is necessary, starting with the etching of an intermediate mask (e.g. SiNx). The hole patterns are defined by electron beam lithography [1], which is still required for the fabrication of thick and highly resistive masks.

Chemically assisted ion beam etching (CAIBE) is a suitable tool for the final crucial deep etching step (Fig. 1). In this technique a drastic RIE lag making very small structures very shallow is not present. In this way much larger aspect ratios than with standard RIE (reactive ion etching) can be obtained (Fig. 2), thus exponentially decreasing the scattering losses in PhC waveguides.



Two adiabatic field transformers [2] are used for efficient coupling from an optical fibre to a PhC waveguide. First a planar adapter section transforms from the fibre interfacing facet to a standard optical board waveguide. Then a field transformer with a vertical taper section is used for coupling into the PhC (Fig. 3). This design allows for the compensation of effective index contrast and field width mismatch (about 500 nm in PhC waveguide with one missing row).

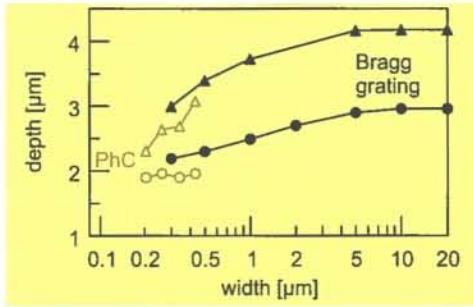


Fig. 2:
Structure depth achieved by two CAIBE processes, with high (triangle) and low (circle) chemical contributions

The work is supported by the Federal Ministry of Education and Research under grant 13B82428.

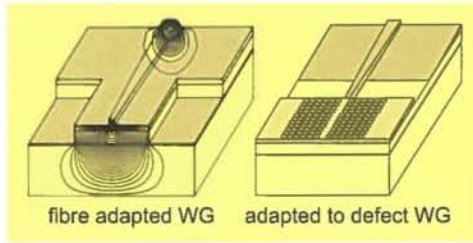


Fig. 3:
Schematic of an adiabatic field transformer

[1] R. Steingrüber, S. Golka and H. Heidrich, "Useful and cost efficient fabrication of dot arrays for photonic crystals by direct write electron-beam lithography", Proc. MNE '02, Lugano, Switzerland, September 2002, pp. 138-39.

[2] H. Heidrich and C.M. Weinert: "Integriert optischer Feldweitentransformator zur adiabatischen monomodigen Feldanpassung", Patent Application DE 10123137C1 (30.4.2001).

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Fig. 1:
SEM image of deeply etched PhC material fabricated using chemically assisted ion beam etching (CAIBE). The pitch is 420 nm. The field of the planar waveguide mode is sketched at the left.

40 Gbit/s Balanced Photodetector Module Based on InP

A high speed monolithically integrated balanced photodetector is presented. The detector module has a 3 dB bandwidth of 34 GHz and a broadband common-mode rejection ratio of more than 20 dB, and is suitable for operation in 40 Gbit/s transmission systems.

A balanced photodetector is a key element for direct detection in differential phase shift keying (DPSK) transmission formats in which a bipolar reception scheme is desired. Monolithically integrated balanced waveguide photodetectors provide excellent RF matching of both photodiodes, broad bandwidth, high power capability and low packaging cost. The design of the integrated balanced photodetector based on InP is shown schematically in Figure 1. It contains two spot-size transformers, two waveguide S-bends and a pair of high-speed pin photodiodes (PD1 and PD2) with high power capability. The evanescently coupled photodiodes are located on top of the waveguide layer stack and are biased by integrated bias circuits. The photodiodes are electrically connected in an anti-parallel configuration; with the currents subtracted directly on chip. This improves the RF performance at high frequencies.

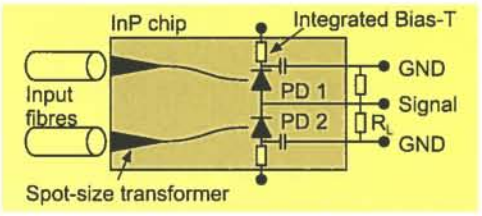

Fig. 1: Schematic view of the integrated balanced photodetector

Figure 2 shows the packaged balanced detector module, with two fibre input connectors, two pins for biasing and the coaxial output port. The detector has an electrical 3 dB cutoff frequency of 34 GHz and narrow pulse widths of 15 ps. Experiments demonstrate a high degree of symmetry between the photodiodes up to signal frequencies of 30 GHz, which is due to our compact monolithic integration scheme. This results in a broadband common-mode rejection ratio of more than 20 dB [1].

We tested the detector in first experiments with a DPSK modulation format at 40 Gbit/s, using a zero-biased Mach-Zehnder modulator in push-pull configuration and an optical delay line demodulator. The received eye pattern of a pseudo-random bit stream of length 2^{15}-1 at an input power of 10 dBm is clearly open (Figure 3). The receiver sensitivity for BER = 10^{-9} is better than -29 dBm.

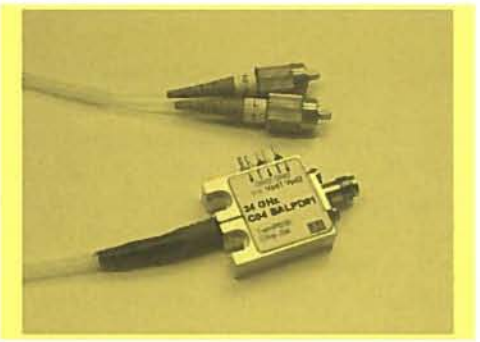

Fig. 2: Balanced photodetector module

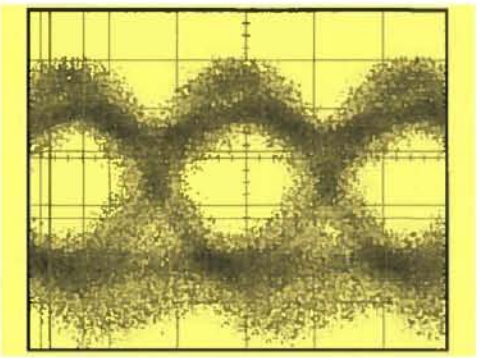

Fig. 3: Eye diagram of a 40 Gbit/s DPSK bit stream (10 ps/div, 30 mV/div)

[1] A. Beling, H.-G. Bach, D. Schmidt, G.G. Mekonnen, M. Rohde, L. Molle, H. Ehlers and A. Umbach, "High-speed balanced photodetector module with 20 dB broadband common-mode rejection ratio", Proc. Optical Fiber Commun. (OFC 2003), March 23-28, 2003, Atlanta (GA, USA), paper WF4.

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60 Gbit/s Photoreceiver Modules using InP OEICs for Direct Interfacing to a Demultiplexer Without a Bias-T

A fully packaged InP-based photoreceiver, comprising a waveguide-integrated photodiode and a travelling wave amplifier, is presented. The interface to the following electronics is dc-coupled, which avoids the usual bias-T. It functions at data rates up to 60 Gbit/s with NRZ modulation.

Although there is a continuing trend to upgrade the world-wide high-speed transmission core networks to bit rates of 40 Gbit/s, even higher rates are of interest to optimise the transport capacities of the fibre networks. Monolithic opto-electronic integrated receivers based on InP, operating at a wavelength of 1.55 mm, are the most promising candidates for high bitrate transmission systems at 40 Gbit/s and beyond.

Figure 1 shows the circuit design of the pinTWA [1] photoreceiver OEIC. A newly added metal-insulator-metal (MIM) capacitor (100 pF) separates the dc potentials of the amplifier ground and the high frequency output. The output can be adjusted to zero bias or to an arbitrary potential, depending on the needs of the subsequent electronics.

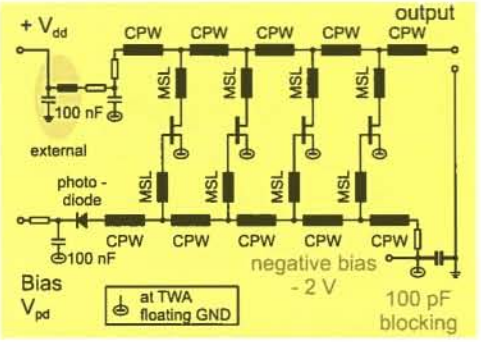

Fig. 1:
Circuit schematic of the pinTWA photoreceiver OEIC with a dc-coupled output to the following electronics. The dc decoupling of two ground potentials of the OEIC is provided by the integrated 100 pF MIM blocking capacitor.

The InP-based photoreceiver is realized by integrating a waveguide-integrated photodiode together with a spot-size converter and a special high-electron mobility field effect transistor (HEMT)-based travelling wave amplifier (TWA). The OEICs were fabricated using a two-step MOVPE/MBE epitaxial approach for the waveguide-integrated photodiode HEMT layer stacks, thereby allowing the individual devices to be independently optimised. Figure 2 shows the fabricated OEIC.

Characterization was done by the optical heterodyne measurement technique. The bandwidth exceeded 50 GHz.

Figure 3 shows the measured eye pattern at 40 Gbit/s. The eye is wide open, so that higher bitrate capability may be presumed.

Due to the lack of measurement capabilities at higher bitrates, the eye pattern was deduced synthetically by FFT/IFFT methods in a circuit simulator. The minimum phase of the receiver was calculated from the measured magnitude response using the Hilbert transform, and this was then used to derive eye patterns at arbitrary bit rates (Fig. 4). Even at 60 Gbit/s the eye is well opened, and the STM64 mask is unaffected.

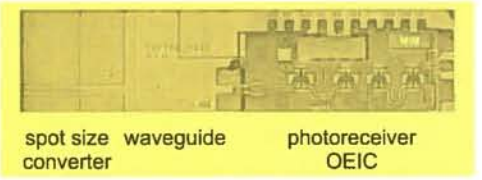

Fig. 2:
Photoreceiver OEIC with RF and dc ground pads decoupled by MIM capacitors (dotted white line)

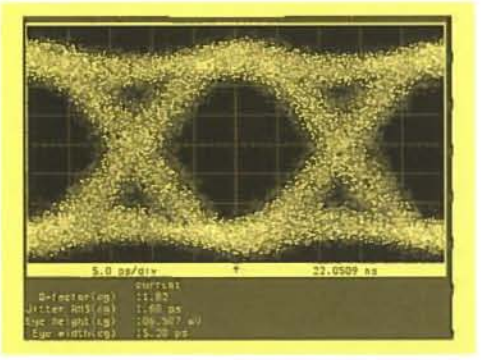

Fig. 3:
Measured 40 Gbit/s NRZ eye pattern of the photoreceiver module at -1.6 dBm using a PRBS of length 2^{31}-1

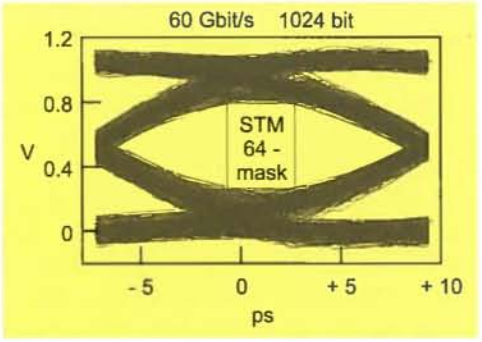

Fig. 4:
Calculated eye pattern at 60 Gbit/s using NRZ modulation (1024 bits)

[1] H.-G. Bach, A. Beling, G. G. Mekonnen and W. Schlaak, "Design and fabrication of 60 Gbit/s InP-based monolithic photoreceiver OEICs and modules", IEEE J. Select. Topics Quantum Electron. (Issue: Integrated Optics and Optoelectronics), vol. 8, pp. 1445-1450, Nov./Dec. 2002.

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Full On-Wafer Fabrication of a Bottom-Emitting 1.3 µm Buried Heterostructure Fabry-Perot Laser with Integrated 45° Reflector and Monitor Photodiode

We realized a bottom-emitting OEIC, including laser, monitor photodiode, and prism, in a monolithic integrated form suitable for surface mount technology (SMT) packaging. The fabrication of the laser and the reflection mirrors in full-wafer technology exploits the cost-efficiency advantages of on-wafer facet preparation and on-wafer characterization.

Packaging of laser OEICs in lead frame technology for plastic SMT packages (e.g. TSSOP10) is a novel, less expensive approach as compared to the use of metal housings such as butterfly, DIL or TO. In SMT packages the beam of an edge-emitting laser chip is directed via prisms or mirrors so that it emits at right angles to the mounting plane.

We realized a complete monolithic solution including a 1.3 µm buried heterostructure Fabry-Perot (BH-FP) laser, an optical field transformer to reduce the far-field angle to less than 22° at 3 dB, a 45° beam reflector for bottom emission and a monitor photodiode in the beam propagation direction (Fig. 1) [1]. The fabrication of the laser and reflection mirrors in full-wafer technology reduces cost due to on-wafer facet preparation and on-wafer characterization.

Fabrication starts with standard BH-FP laser processing. The photodiode epitaxial layer stack is grown together with the laser cladding layer. The laser resonators and photodiode mirrors are then etched using a chlorine-based chemically assisted ion beam etching process (CAIBE) (Fig. 2). Aging measurements show no degradation due to the etched mirrors. Lifetimes exceeding 105 hours are estimated by extrapolation.

The 45° totally reflecting mirrors are etched at low temperature with an accuracy better than 1° using an HBr:HCl solution. The antireflection coating of the photodiode input side and the reflection coating of the laser backside are deposited on-wafer. The complete element is sealed with photosensitive CYCLOTENE™ 4000 series from DOW, which reduces the far-field laser angle due to its refractive index (1.54).

The photodiode current corresponding to a laser output power of 10 mW is 1.5 mA. The responsivity of the monitor photodiode was nearly constant at 0.13 A/W over a 40 mA range of laser current (Fig. 3). The photodiode dark currents are less than 20 nA at 5 V.

The die size and overall performance are comparable to hybrid solutions.

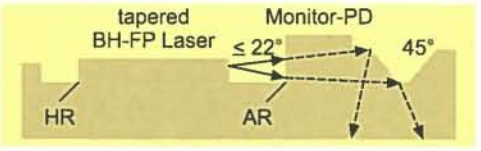

Fig. 1: Device architecture (HR/AR: highly reflective/ antireflective coating)

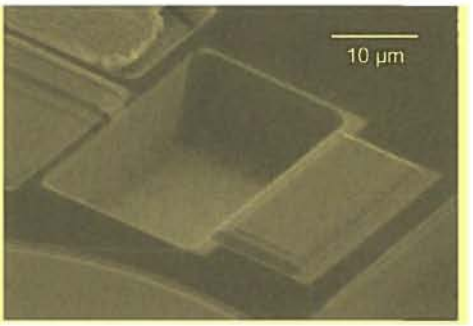

Fig. 2: SEM view of CAIBE-etched front-side Fabry-Perot resonator and photodiode

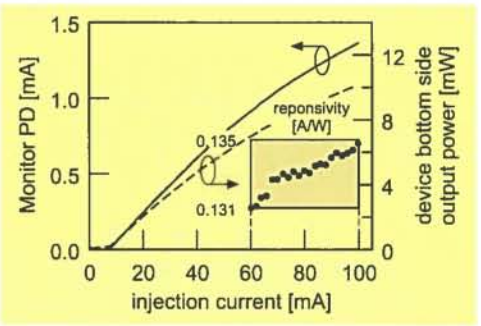

Fig. 3: Bottom side laser output power and monitor photodiode current

This work was performed under a subcontract from Infineon Technologies AG.

[1] K. Janiak, P. Albrecht, S. Fidorra, H. Heidrich, W. Rehbein, H. Roehle and H.-L. Althaus, "1.3 µm BH-FP laser with integrated monitor photodiode, 45° reflector for bottom side emission employing full on-wafer fabrication", Proc. IPRM 2002, May 2002, Stockholm, Sweden, pp. 31-34, paper MoA1-4, ISBN 0-7803-7320-0.

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A New Approach to the Fabrication of Nanoscale Dot Arrays using Direct-Write Electron Beam Lithography

An easy-to-use procedure for the generation of complex nanoscale two-dimensional dot arrays is presented. The dot elements of the designed patterns are defined as squares instead of circular shapes, which results in a dramatic reduction of the data volume and complexity. Under optimised process conditions the use of rectangularly defined dots results in circular pattern shapes of well controlled dimensions.

The fabrication of nanoscale multiple two-dimensional dot arrays is becoming increasingly important because they are the essential constituents of Photonic Crystals (PhC). The characteristics of PhCs depend crucially on the shape and size of the dots. Therefore direct-write electron beam lithography (EBL) is the technology of choice for generating these structures. Typical PhC dot arrays use pitch sizes and diameters of only a few hundred nanometers arranged in a hexagonal grid, and this pattern will extend over various sub-devices in future integrated PhC components.

The design aspects of PhCs place high demands on data generation and preparation due to the enormous amount of CAD and exposure data required. In our approach we take advantage of the proximity effect during the exposure [1, 2]. This allows us to use rectangularly defined dot shapes instead of circular ones.

The top sequence in Fig. 1 shows the calculated dependence of the nominally circular dot shapes on the chosen resolution during fracturing. The shape of the dots is lost if a coarser resolution is used. In contrast to that, the lower sequence of Fig. 1 shows that for rectangular dots there is no dependence of the shape on the chosen converter address grid. Whereas for circular shapes the amount of data increases quadratically with the applied resolution, we found that for rectangular design the size of the exposure data set is not affected. This simplifies the data management, e.g. proximity correction or dose assignment.

For fabrication by EBL we use a standard vector scan tool and standard high resolution resists. We found best results for a ratio of design width to pitch of 0.4. For example, a 250 nm pitch requires a 100 nm square design width. Figure 2 shows a two-dimensional dot array stripe in resist fabricated using the optimised processing conditions.

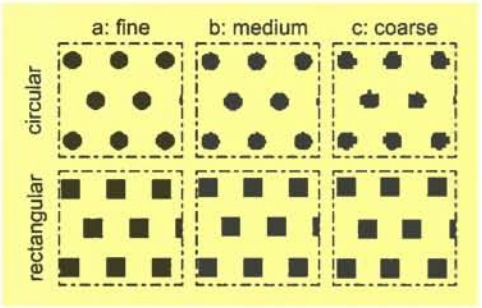

Fig. 1:
Calculated shapes of circular and rectangular dots for different resolutions

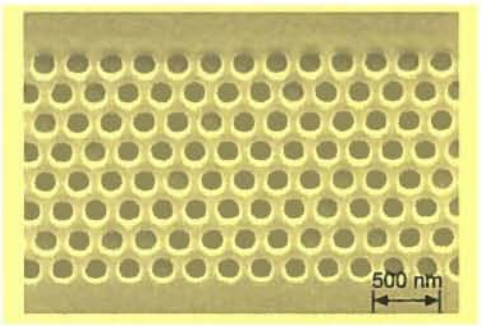

Fig. 2:
SEM photograph of a dot array in resist

This work was supported by the Federal Ministry of Education and Research of Germany under grant 13B82428.

[1] R. Steingrüber, S. Golka, and H. Heidrich, "Useful and cost efficient fabrication of dot arrays for photonic crystals by direct write electron-beam lithography", Proc. MNE '02, Lugano, Switzerland, September 2002, pp. 138-139.

[2] R. Steingrüber, patent application 102 43 827.7, 14.09.2002.

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Silicon-on-Insulator Photonic Crystal Structures for WDM Applications

Filter components are realised that are based on micro-cavities formed by deliberate defects in linear photonic crystals patterned in high index waveguides. The photonic crystal structures are fabricated in silicon-on-insulator (SOI) technology by direct e-beam writing and etching.

Photonic crystals (PhC) are artificial periodic structures with high refractive index contrast in which the periodicity is on the scale of the wavelength of light. Photons travelling through such a lattice encounter a band of wavelengths which cannot propagate and which are therefore completely reflected. This photonic bandgap (PBG) behaviour is analogous to the electronic bandgap for electrons travelling through the periodic potential of a semiconductor lattice. PBG materials also offer a method of realizing highly confined optical states by the insertion of local defects into a PhC. These constitute resonant cavity modes and appear as sharp transmission lines inside the forbidden band.

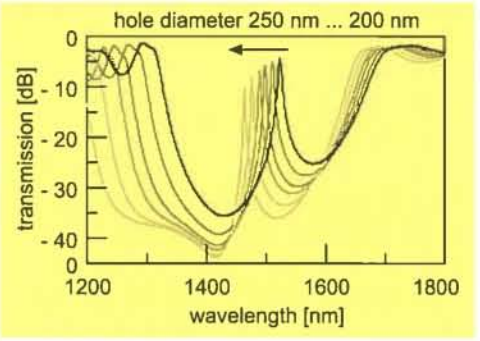

Fig. 1: Calculated transmission of a linear hole grating with defects in a single-mode SOI waveguide

Photonic crystals have attracted great interest because of their potential to control light wave propagation and to implement PhC-based optical filters in WDM systems. Since 3D PhCs are difficult to fabricate, an alternative is to use waveguides for lateral light confinement, combined with a periodic array of holes which forms a linear PhC. A defect included in this PBG structure can create a local cavity mode that can act as an optical filter.

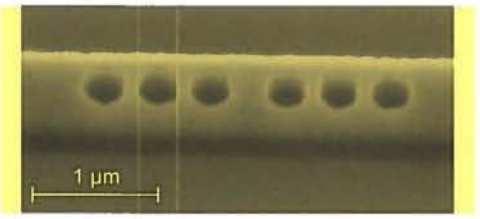

Fig. 2: REM picture of a fabricated PhC micro-cavity structure in SOI with 2 x 3 holes and a gap between them

Extending the optical waveguides at both sides of the PhC gives efficient light coupling to the PhC micro-cavity. Unlike 3D photonic micro-cavities, light confined in an index-guided structure also couples to radiation modes, leading to increased loss in the transmission lines. These structures must therefore be designed carefully to realize cavities with high quality and low losses.

We have calculated the PhC micro-cavity behaviour in single-mode SOI waveguides with air-filled holes using the 3D FDTD (finite differential time domain) method. Figure 1 shows for example the calculated transmission behaviour of a row of 2 x 4 holes (with a 450 nm period and a 650 nm gap between the groups) in a 200 nm thick and 500 nm wide silicon strip waveguide. The hole diameters vary between 200 nm and 250 nm, resulting in a bandgap of about 400 nm [1].

Figure 2 is a REM picture of a PhC micro-cavity structure fabricated in SOI (200 nm silicon layer on top of 2 µm thick SiO_2) by e-beam writing and anisotropic etching. The etched holes are about 500 nm deep and 250 nm in diameter.

The sample transmission was measured in the wavelength range 1450-1550 nm using a tunable laser source. The result is shown in Fig. 3, in which a transmission peak at 1475 nm is evident.

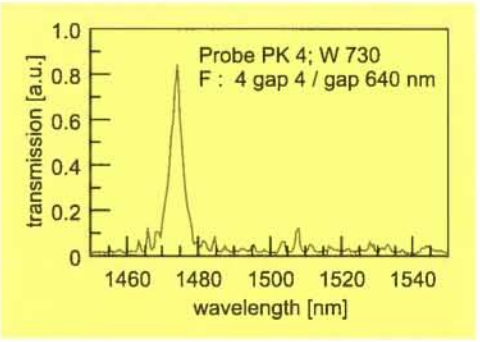

Fig. 3: Measured filter behaviour of a PhC micro-cavity in SOI with 2 x 4 holes and a gap size of 640 nm

[1] G. Przyrembel, B. Kuhlow and S. Schlüter, "Flat-top transmission waveguide filter with multiple cavities", Proc. Workshop and EOS Topical Meeting on 2D Photonic Crystals, pp. I-20, Ascona (CH), Aug. 25-30, 2002.

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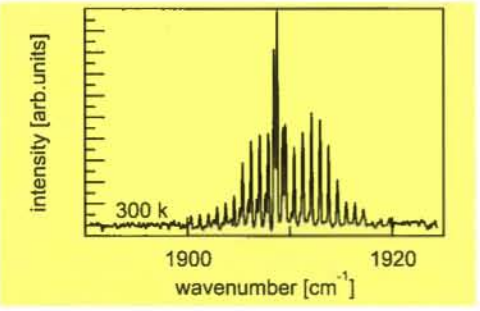
Intersubband Emitters Based on InP

Intersubband transitions in multiple quantum well structures are attractive for long-wavelength emitters (quantum cascade lasers) and potentially also for ultra-fast optical switches and optical amplifiers in telecom applications. Quantum cascade laser (QCL) devices operating at 5 µm wavelength and up to 300 K have been fabricated in GaInAs/AlInAs technology. To shift the wavelength towards 1.55 µm for fibre-based communication, molecular beam epitaxy growth of GaInAs/AlAsSb quantum wells on InP has been commenced.

The utilization of intersubband transitions in semiconductor multiple quantum wells (MQW) is attractive for realizing ultra-fast photonic devices due to their ultra short carrier relaxation times and the pronounced optical nonlinearities inherent in these transitions. Light sources, optical amplifiers and optical switches for ultra-high bitrate optical fibre transmission might possibly be realized by employing intersubband transitions. In this context HHI is member of the Berlin-based joint research group "Light emitters based on intersubband transitions", which aims to achieve a detailed understanding of intersubband emitter structures as well as their implementation in devices (QCLs).

In the first stage of research, MBE growth and processing technology for QCLs were developed using the design in [1] for conventional strained GaInAs/AlInAs layers on InP. Early 27 µm wide devices showed laser emission up to 300 K (Fig. 1) with a 300 K threshold of 3.8 A (pulsed).



Using GaInAs/AlInAs QCL structures, even with strained layers, the emission wavelength is limited to IR wavelengths above 3.5 µm. In principle, this wavelength range could be extended to shorter values, approaching 1.55 µm, which are relevant for fibre-based communication, by incorporating barrier materials with larger band gaps in the QCL active region. On InP a potential candidate is AlAsSb (lattice-matched at x_{Sb} = 0.44), which due to its large band gap has a conduction band edge discontinuity of roughly 1.7 eV. An intersubband transition wavelength of 1.55 µm has recently been deduced from IR absorption for such MQWs [2].

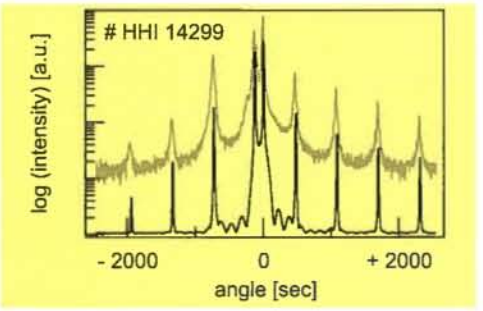


Fig. 2:
X-ray diffraction pattern of a 50-period 3 nm/30 nm GaInAs/AlAsSb MQW (grey line: measured, black line: modelled)

We have achieved first lattice-matched GaInAs/AlAsSb MQWs with well thicknesses between 2 nm and 4 nm that are adequate for 1.55 µm intersubband transitions. The perfect agreement between the measured and modelled x-ray diffraction spectra in Fig. 2 indicates the high quality of the epitaxial layers. In addition, based on the agreement between 300 K photoluminescence measurements and simple calculations (e.g. using the parabolic approach), the electronic structure of the GaInAs/AlAsSb MQWs was investigated. Thus, the MBE growth basis for reduced wavelength QCLs and terabit per second all-optical switches has been established.

This work is sponsored by Deutsche Forschungsgemeinschaft (DFG) as FOR394 and was performed partially in collaboration with the TU Wien.

Fig. 1:
300 K laser spectrum of a strained GaInAs/AlnAs QCL (with pulsed excitation

[1] D. Hofstätter, M. Beck, T. Aellen and J. Faist, Appl. Phys. Lett., 78, 396 (2001).

[2] T. Mozume, H. Yoshida, A. Neogi and M. Kudo, Jpn. J. Appl. Phys., 38, 1286 (1999).

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Wavelength Trimming of All-Polymer Athermal Arrayed Waveguide Multiplexers

A novel post-fabrication refractive index trimming technique is reported for adjusting the central wavelengths of all-polymer athermal arrayed waveguide grating multiplexers to the standard ITU frequency grid.

WDM demultiplexer components featuring temperature-independent wavelength channels are highly attractive for cost reasons. Recently we have introduced such a demultiplexer based on an athermal arrayed waveguide (AWG) built entirely on polymer materials [1]. A key issue arising with such athermal AWGs is, however, the fine tuning of the wavelength channels to the standard ITU grid. Conventional adjustment techniques based on heaters or coolers are not useful for this purpose. We have therefore investigated gamma (γ) irradiation as a potentially powerful trimming method.

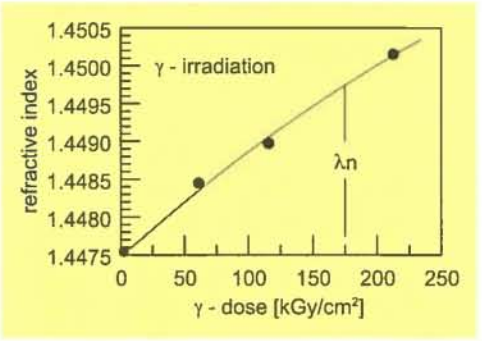

Fig. 1: Effect of γ irradiation on refractive index

The central wavelength of an AWG is given by:

$\lambda_c = n_c \cdot \Delta L/m$,

where λ_c is the central wavelength, n_c the effective refractive index of the arrayed waveguide, ΔL the path length difference between neighbouring waveguides, and m the grating order. It is apparent that the central wavelength is essentially determined by the effective refractive index of the waveguide. The use of γ-rays was considered an efficient way to modify this parameter and thus the AWG wavelength.

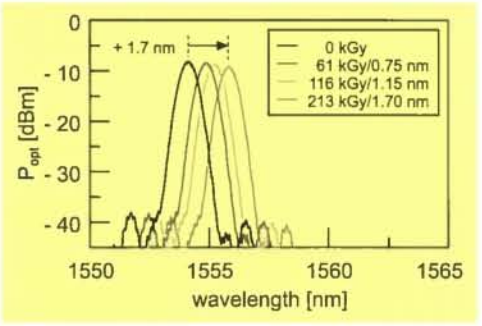

Fig. 2: Wavelength shift of an AWG as a function of the γ-ray dose

All-polymer athermal 8 x 8 AWG routers with $\Delta\lambda$ = 200 GHz at λ = 1.55 µm were produced by properly matching the coefficient of thermal expansion of the polymer substrate to the thermo-optic coefficient of the polymer waveguide. Gamma irradiation was applied to the completed chips. Figure 1 shows the measured results of the index change as a function of the γ-ray dosage. An index increment of 0.003 was obtained at a γ-ray dose of 200 kGy/cm^2. Respective trimming results for an AWG router are shown in Fig. 2. A wavelength shift of 1.7 nm was obtained at a γ-ray dose of 213 kGy/cm^2 [2]. This wavelength shift is larger than the channel spacing of a 200 GHz AWG.

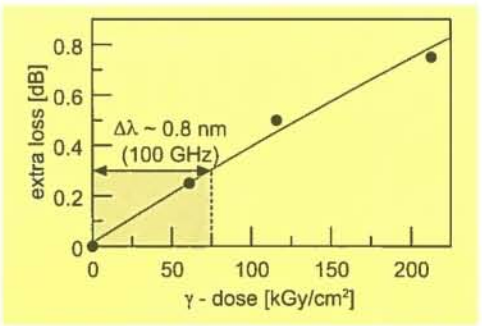

Fig. 3: Irradiation effect on insertion loss

The measured excess insertion loss due to γ-ray irradiation is shown in Fig. 3. The induced extra loss can be seen to be less than 0.3 dB for a 200 GHz AWG, requiring a worst-case trimming range of 100 GHz.

This work was performed in cooperation with FhG IZM/EPC, Teltow, Germany, and with Gamma Bestrahlung GmbH, Radeberg, Germany, and was partially supported by the Federal Ministry of Education and Research under grant 01 BP 150.

[1] N. Keil et al., Conf. Dig. OFC 2001, Post-Deadline Session, PD7, 2001.

[2] N. Keil et al., Conf. Dig. ECOC 2002, 6.2.3, 2002.

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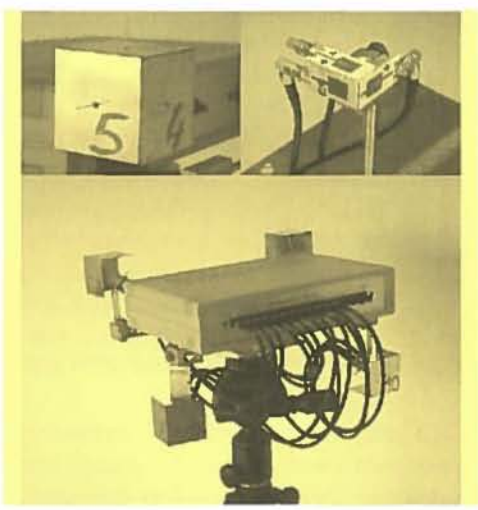
Measurements of the Capacity of MIMO Radio Systems in Indoor Environments

Measurements of the capacity of Multiple-Input Multiple-Output (MIMO) radio systems with large numbers of antennas were conducted at 5.2 GHz. With triple antennas at the corners of a laptop-like chassis, a linear relation between the capacity and the number of antennas was observed in non-line-of-sight (NLOS) environments, consistent with results from information theory. The degradation due to the line-of-sight (LOS) signal is usually small when antenna elements have omni-directional characteristics.

Recent results from information theory have shown that the capacity of radio systems may be increased linearly with the number of antennas when multiple antennas are used at both the transmitter (Tx) and receiver (Rx) and when the Rayleigh fading between pairs of antennas is independent.

In order to evaluate the potential of MIMO techniques, channel measurements were conducted at HHI in cooperation with MEDAV GmbH, Uttenreuth.



The antenna arrangement is shown in Fig. 1. The basic element is a λ/4 monopole with omni-directional characteristic. We use 3 monopoles forming a triple antenna to exploit the independence of the fading field components (top left). Monopoles could be replaced by patch antennas in practical applications (top right). A triple antenna is mounted at each corner of a laptop-like chassis so that the equally directed elements have large spacings and the fading tends towards independence (bottom). The arrangements at the transmitter and receiver were similar.

Individual channels between each pair of Tx and Rx antennas were measured with the RUSK ATM channel sounder in the 5.14 – 5.26 GHz frequency range. All channels were measured in a total time of only 1 ms, which is short compared to the time in which channel properties may change. The MIMO capacity was obtained from the measurement data of a static configuration after averaging over 50 snapshots to reduce the noise. Typical measured SNR values are in the 35 – 45 dB range to reliably estimate the capacity for link SNR values up to 20 dB. The mean path loss was averaged out to compare the measurements with the theory.

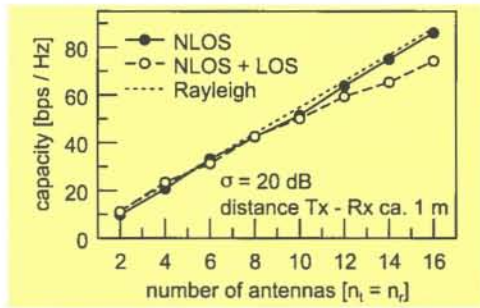


Fig. 2:
Measured MIMO capacity as a function of the number of antennas

The measurement results are shown in Fig. 2. The dotted line shows the theoretical values for independent Rayleigh fading. The full circles are the measured results when the LOS was blocked by an absorber mat with more than 20 dB attenuation. The measurements agree very well with the theoretical results in the absence of a LOS signal. Spectral efficiencies better than 80 bps/Hz are indeed achievable at reasonable link SNRs (20 dB) with 16 transmit and receive antennas. When the LOS is included, some minor degradation is observed if there are more than 10 antennas.

Even at relatively small distances between Tx and Rx antennas (1 m), the increase of correlation due to the LOS signal remains small. This is related to the somewhat unexpected fact that scattering is quite significant with omni-directional antennas, so that the direct signal is not as important. Note that the antenna arrangement has a large impact on the achievable capacity [1].

Fig. 1:
Antenna arrangements used for MIMO channel measurements

[1] V. Jungnickel et al., Proc. WPMC, 27-30 October, 2002, Honolulu, Hawaii.

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Adaptive Signal Processing for Singular MIMO Channels

MIMO capacity may be reduced in propagation scenarios where there is little scattering. By using well known reduced-complexity signal processing algorithms, such as V-BLAST, the probability of outage may become rather large in such channels. Adaptive channel inversion (ACI) is a simple scheme to combat these problems, provided that channel state information (CSI) is available also at the transmitter.

It is well known that the capacity of MIMO systems may be reduced when there is little scattering. The channel matrix H describing the transmission from each transmit (Tx) to each receive (Rx) antenna may then be singular. Consider the well known singular value decomposition $H = U \cdot D \cdot V^H$, where U and V are unitary matrices, D is a diagonal matrix with ordered singular values (SVs) on the main diagonal, and the superscript ^{H} indicates the hermitian transposition. We observe that one or more SVs are close to zero when scattering is rare, so that H is close to singular in this case. There will be no pseudo-inverse matrix enabling separation of data streams sent in parallel over that MIMO channel.

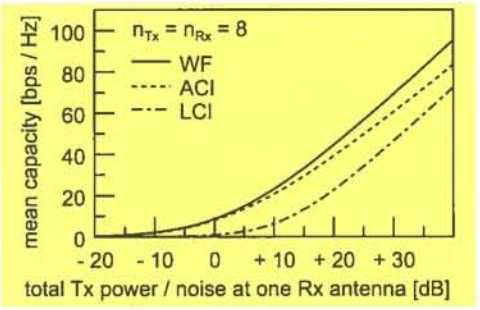

Fig. 1: Mean MIMO capacity for different pre-processing schemes

Reduced complexity MIMO processing schemes based on the pseudo-inverse matrix, such as V-BLAST, must therefore be extended by bit loading algorithms applying adaptive coding and modulation in each stream. But still, only a single stream may be transmitted in a truly singular channel.

In wireless systems operating in time-division duplex mode (e.g. UMTS-TDD and 802.11), CSI for the downlink may be obtained from the uplink, and vice versa, using channel reciprocity.

In this case we can employ ACI for reliable transmission of multiple streams. This technique is based on the well known "eigenmode signalling" method in which each data stream is assigned to a corresponding SV by pre-processing the data vector d_{red} by $x = V \cdot D^{-1} \cdot d_{red}$, where x is the Tx signal vector and D^{-1} is the pseudo-inverse of D, and then post-processing the Rx signal vector y by $d_{red}' = U^H \cdot y$.

The length of the data vector d_{red}, i.e. the number of active streams n_d, may then be chosen to maximize the throughput. In this way data signals will not be assigned to the critical singular values close to zero.

The capacity of ACI with optimal n_d is compared in Fig. 1 to the ultimate water-filling (WF) and linear inversion (LCI) methods, where n_d is maximal. Obviously, ACI approximates WF at low power, where only a single stream at full power is supported by either scheme. Also, higher power is required for a given capacity with LCI because of the small SVs [1]. Clearly, avoiding critical SVs by reducing n_d increases the capacity.

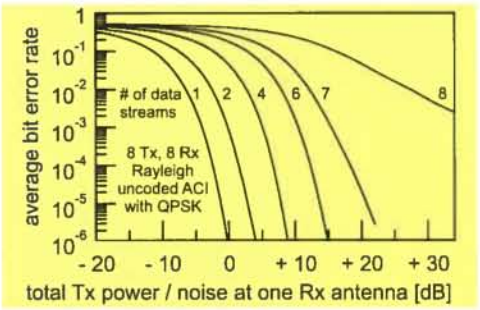

Fig. 2: Bit error rate of ACI with reduced numbers of streams nd

ACI also allows a step-wise trade-off between spatial multiplexing (i.e. parallel transmission of data streams) and diversity, as shown in Fig. 2. When the maximum number of streams is used, a huge power is needed to achieve a small bit error rate, and the slope of the curve indicating diversity order is rather small. But as soon as one or more streams are switched off, much less power is needed and the diversity order is significantly increased. Transmission is more reliable in that case.

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MIMO with OFDM for Future 4G Wireless Systems

Orthogonal frequency division multiplexing (OFDM) in combination with multiple antennas (MIMO) is a possible communication technique for existing as well as future 4G wireless systems. In this work we investigate the peak-to-average power ratio (PAPR) of the transmitted signals, the achievable channel capacity, channel estimation schemes, and space-frequency codes. The PAPR problem is still the major obstacle to implementing OFDM in low-cost applications.

Fourth generation mobile systems must be designed to meet the ever-increasing demand for bandwidth in a flexible and low-cost manner, and the combination of OFDM and MIMO appears to be a promising candidate for this application. There are two main reasons underlying this assertion: multiple antennas were recently shown to increase the overall capacity to enormous values, while OFDM provides scalable and flexible transmission and, most importantly, requires only a very simple equalisation scheme. However, major obstacles to the deployment of this capacity are: 1) the high PAPR of the transmitted signal, and 2) channel impairments due to user mobility.

The main disadvantage of OFDM transmission is the high PAPR. For example, if the peak power is limited by a regulatory body, the average power allowed under OFDM is lower than with constant power modulation. Moreover, the transmitter power amplifier must operate in a power-inefficient region. Also, limited 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. In [1, 2] a new approach was presented that can be used to bound the distribution of the PAPR for both uncoded and coded systems. From this analysis characteristic parameters can be obtained for the OFDM system designer, such as the maximum PAPR and the "effective" PAPR, which is defined as the PAPR at which the probability of errors can be considered negligible in practice. The impact of the clipping rate on the performance was considered in [3], which gives insight into the nature of clipping in terms of the level-crossing statistics of OFDM signals. Using the approach in [1, 2], new codes with low PAPR were recently designed that show better performance than the common schemes and suggest interesting conclusions about the triple code rate, minimum distance and PAPRs for codes.

Another disadvantage is the impact of the mobile channel, which forces the system to adapt to the channel. Taking into account that future wireless systems are expected to operate in highly mobile environments, the time needed for channel estimation for MIMO systems can become a significant part of the communication time, and the system performance will strongly depend on the quality of the estimation schemes. It was shown that a very efficient pilot-based estimation scheme can be devised that depends on the number of subcarriers, representing the degrees of freedom in the system, the number of transmitter antennas and the channel delay profiles. This scheme also has low PAPR. The fundamental limits of this scheme in terms of the pilot signals were also investigated and outlined.

This work was supported by the Ministry for Education, Science, Research and Technology of the Federal Republic of Germany under Grant No. 01BU150.

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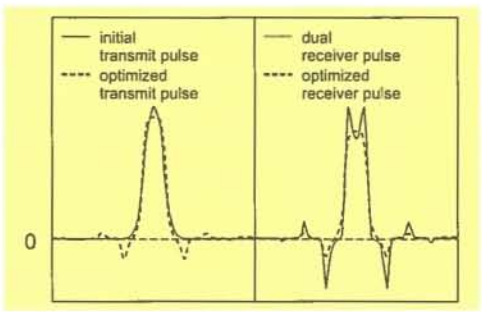
Bandwidth-Efficient Non-Orthogonal Multicarrier Transmission Schemes

Multicarrier transmission schemes are promising candidates for next generation broadband wireless communication systems. A number of new techniques were recently proposed to increase the spectral efficiency and adaptivity in time-variant channels. In this work we characterize these systems in terms of several system performance parameters.

In multipath channels, conventional multicarrier (MC) transmission using subcarriers benefits from the lower time dispersion per subcarrier, which is due to the larger symbol lengths. This leads to reduced intersymbol interference, compared to a single carrier system operating at the same data rate. Obviously this choice of the carriers matches the time-invariant channel. The most popular MC setup for this situation, orthogonal frequency-division multiplexing (OFDM), has already been implemented in several standards such as DAB and DVB-T.

Extending this concept to the time-varying channel leads to the question of how to find the optimal carrier pulse shapes to minimize the intercarrier and intersymbol crosstalk. The mean time-frequency power profile of the channel gives rise to a partition of the time-frequency plane into uncorrelated regions. It is intuitively clear that the optimal carriers have to match this time-frequency profile. Such adaptation to the channel requires control over the transmitter and receiver pulse parameters, especially their localization, which is not possible with the conventional OFDM scheme. Having this picture in mind, and additionally motivated by the reduced spectral efficiency of OFDM due to the cyclic prefix, several authors have proposed new MC transmission techniques, mostly based on DFT filterbanks.

In [1] we established a generalized formulation of linear multicarrier transmission schemes. Using this concept we found a description of the most basic time-variant distortion, the frequency offset. This work covers the framework of biorthogonal frequency-division multiplexing (BFDM) [2] and Bandwidth Efficient Nonorthogonal Multicarrier Transmission (NOFDM) established in [3]. The motivation behind this is to study the effect of carrier frequency mismatching as well as take the first steps towards exploring time-variant channels. We confirmed the theoretical description of the mean square error and the interference power caused by the frequency offset with simulations, and studied their impact on the symbol error rate.



Pulses with good and symmetric TF localisation before and after pulse shaping

Further we showed that careful pulse shaping, as in the figure, significantly improves the performance of the BFDM/NOFDM approaches.

Finally, the resulting multicarrier design procedure results in a robust transmitter and receiver setup for given requirements of spectral efficiency and constraints on pulse shapes.

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

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Sum-Capacity Optimization of the MIMO Gaussian Multiple-Access Channel

We study the sum capacity of a Gaussian multiple-input multiple-output multiple-access channel with a sum power constraint. In order to develop an efficient algorithm for maximizing the sum capacity, we extend recent results about the duality between the vector multiple access broadcast channel and the Sato bound. We extend the iterative water-filling algorithm from [1] to obtain the optimum power allocation.

It is now well known that multiple-element antenna arrays can improve the performance of a wireless communication system in a fading environment. The single-cell multiuser scenario, in which each mobile is equipped with a number of transmit antennas and the base station has many receive antennas, is called the multiple-input multiple-output (MIMO) multiple-access channel (MAC).

The analysis of the theoretical limit of the information that can be successfully transmitted from the users to the base station is a difficult problem due to the large number of free parameters in the transmitter covariance matrices at the transmit antenna arrays. One main performance parameter of interest is the sum capacity of the MIMO MAC.

$$\max_{\sum_{i=1}^{K} tr(S_i) \le P} \log\det\left(\mathbf{I} + p\sum_{k=1}^{K}\mathbf{H}_k\mathbf{S}_k\mathbf{H}_k^H\right)$$

In [2] we optimize the sum capacity of the MIMO MAC under the sum power constraint by first separating the optimization problem into two coupled optimization problems: the covariance matrix optimization and the power allocation problems. The covariance matrix optimization problem for fixed power allocation was solved in [1]. The iterative waterfilling algorithm yields the optimum transmit covariance matrices for a given signal-to-noise ratio (SNR) and power allocation. The power optimization problem for fixed covariance matrices can be solved by interior point methods because the sum capacity is a concave function of the power allocation.

By alternating between the covariance matrix optimization and power allocation problems, we obtain an iterative solution for the optimum transmit covariance matrices that solves the sum capacity optimization problem. In [2] we simplify this approach to obtain a less complex algorithm that leads to the same optimum solution. Both algorithms have the property that the sum capacity is increased at every iteration step. The algorithms are stopped when the power optimization step leads to the same power allocation as in the previous iteration.

The Sato bound offers an alternative approach for finding the sum capacity point of the MIMO MAC. The Sato bound is the capacity of the cooperative system with worst case noise. It gives an upper bound of the capacity region of the MIMO MAC. At the sum capacity point the Sato bound is tangential to the capacity region. In [2] we develop an algorithm that iteratively computes the sum capacity. First we compute the transmission strategy that maximizes the capacity, and then the noise covariance matrix that minimizes the capacity. This can be modelled as a two player game in which one player wants to transmit as much information as possible while the other player chooses the noise that most disturbs the transmission. This min-max problem leads to a saddle point that corresponds to the sum-capacity point of the MIMO MAC. We characterize this saddle point and develop an algorithm that can find it for a given SNR and a given channel realization.

Future work includes the fairness issues in MIMO MAC transmission scenarios. Each user has their rate requirement depending on the service they are using. The satisfaction of rate requirements is still an open research problem.

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

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Duality Between Multiuser Beamforming Transmission in the Uplink and Downlink

Downlink multiuser beamforming is more complicated than the corresponding uplink problem because of the special crosstalk structure of the downlink. We show that both channels are closely linked by a duality relation. This leads to efficient algorithmic solutions, which can be found by focussing on the easier-to-handle uplink.

The spectral efficiency of interference-limited cellular wireless systems can be significantly increased by using multiple antennas for each communication link. By spreading the signals over the antennas we can exploit the spatial diversity and multiplexing gain offered by the multipath propagation channel. The spatial domain can be viewed as an additional resource to the classical resources, bandwidth and power.

The potential capacity gains come at the cost of increased hardware infrastructure, depending on the number of additional antennas. Since the mobile stations (MS) are typically small low cost hand-held devices, it is desirable that all complexity resides at the base station (BS). Thus, beamforming with multiple BS antennas and a single MS antenna has recently attracted significant interest and is considered a key technology for fourth generation cellular systems.

Despite significant work done in the area of beamforming, the development of multiuser beamforming in conjunction with the network-level techniques of power control and resource allocation is still not well understood. In particular, the downlink from the BS to the mobile terminals is difficult to handle analytically. This is because all downlink channels are intertwined by mutual crosstalk, which depends on all transmission powers and beamformers, in contrast to the uplink channels, which are only coupled by their power levels. There is a close relation between the downlink beamforming problem and the problem of finding an achievable region for the non-degraded broadcast channel, which is a longstanding and unsolved problem in network information theory.

In [1] the HHI has found a duality between uplink and downlink multiuser channels. In particular, it was shown that under certain conditions the same signal-to-interference-plus-noise ratios (SINR) are achievable in both links, assuming that the same sum power constraint is imposed. Moreover, these levels can be achieved by using the same beamforming solution. This duality holds if either all users have the same receiver noise level or if the channel has the specific structure given in [1].

There is an immediate and useful consequence of this duality result: a solution of the complicated downlink problem can be found by solving the easier-to-handle uplink problem instead. This opens up a way of designing efficient algorithms. This was demonstrated in [2], where a computationally efficient algorithm was developed that controls SINR levels according to individual target thresholds by using a nonlinear beamforming strategy with decision feedback, also known as "dirty paper" pre-coding. This strategy decomposes the channel into a series of sub-channels, each interfering only with subsequent sub-channels. This strategy is optimal in that it achieves the given SINR target thresholds with minimum total transmission power.

Another application of the duality result was presented in [1], where a transmission strategy was proposed that maximizes the total throughput of the downlink multiuser channel for a given sum power constraint. The global optimum is such that only the users with "good" channel states are allowed to transmit at any given time. Such a strategy is advantageous for applications such as delay-insensitive packet-switched traffic.

This work was supported in part by the Federal Ministry of Education and Research (BMBF) under grant 01BU150.

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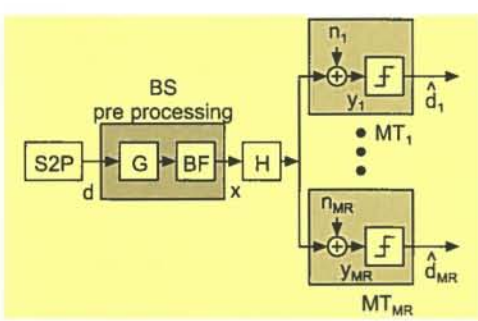
On Power Reduction Strategies for the Multiuser Downlink with Decentralized Receivers

Multiuser transmission systems using multiple antenna arrays at the base station may increase the transmission capacity, or reduce the sum transmit power, significantly. The power reductions with three different downlink transmission schemes is investigated in this work.

If the radio channel is known at the base station (BS), the data can be preprocessed prior to transmission. The data stream is transformed serial-to-parallel, appropriately preprocessed and sent simultaneously with n_T transmit antennas over the radio channel H. The MR mobile terminals receive the signal $y = H \cdot x + n = d + n$ after preprocessing. This corresponds to parallel transmission channels with additive Gausssian noise (AWGN).



Reference [1] proposed a fully decorrelating scheme based on spatial nulling. The preprocessing is done with the Moore-Penrose pseudo inverse of H, but this Joint Transmission (JT) method requires high transmitter power if the channel is not well conditioned.

A more sophisticated concept which also achieves full receiver signal decorrelation is Tomlinson-Harashima Precoding (THP) [2]. Here known interference is eliminated at the transmitter by sending the original signal, but with the known interference subtracted. This technique can save transmit power compared to JT because fewer spatial nulls have to be set.

A new proposal, Joint Costa Beamforming (JCBF) [3], is an optimal downlink beamforming strategy that minimises the transmission power while satisfying individual signal-to-noise-plus-interference-ratio requirements at the mobile terminals.

Figure 2 shows the average power enhancement factor (PEF) compared to parallel AWGN transmission for the investigated schemes. Compared to JT, the nonlinear schemes THP and JCBF save significant amounts of transmitter power. Rural area scenarios with only a few paths and with some users either close to or very far from the BS, for which the matrix H may be ill-conditioned, clearly benefit from the JCBF scheme. The drastic reduction of transmit power is due to the optimal trade-off between decorrelation and noise enhancement. For SINR $\longrightarrow \infty$ the THP and JCBF solutions converge asymptotically.

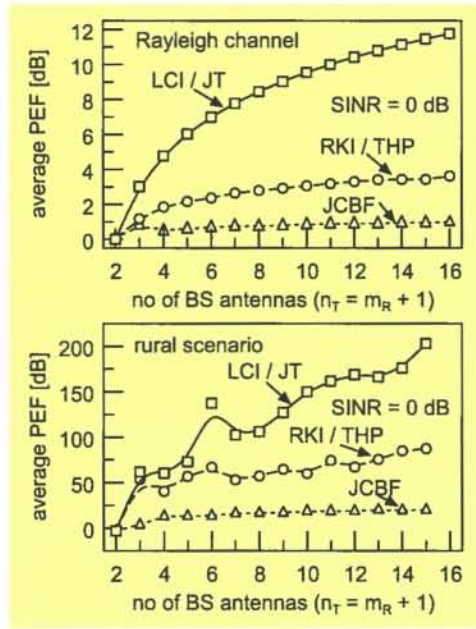


Fig. 1:
Block diagram for data preprocessing at the BS with channel knowledge

Fig. 2:
Power enhancement factors (PEF) for JT, THP and JCBF
(top: Rayleigh channel; bottom: rural area). Note the different dB scales.

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

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Joint Decoding and Channel-Estimation for Low-Complexity Space-Time Coding

In this work we study a low-complexity space-time architecture [1] employing per-survivor-processing with imperfect channel state information (CSI) at the receiver. We analyse the impact of imperfect CSI on the decision metric of the Viterbi Algorithm and on the performance of the architecture. To achieve large spectral efficiency we use only a minimum number of pilot signals for the initial channel estimation. The novel receiver scheme decodes the symbols stepwise and improves the initial channel estimation. We compare our scheme in numerical simulations with other schemes in terms of performance and complexity.

In recent years, the goal of providing high speed wireless data services has generated a great amount of interest among the research community. Recent information-theoretic results have demonstrated that the capacity of the system in the presence of Rayleigh fading improves significantly if multiple transmit and receive antennas are used.

We considered in [2] a wireless Multiple-Input Multiple-Output (MIMO) system with N transmit and M receive antennas. It was assumed that the channel is a flat-fading Rayleigh channel. For this system, the authors in [1] proposed a low-complexity space-time scheme called Wrapped Space-Time Coding (WSTC) to achieve high spectral efficiencies. This scheme works as follows. After encoding the binary sequence with a convolutional code, the bit sequence is then modulated and interleaved using a diagonal interleaver. The data are then transmitted over the *N* transmit antennas. Decoding at the receiver is done by processing according to the interleaver structure. Nulling and cancellation are done using per-survivor-processing, which very effectively reduces the effect of error propagation.

In [1] it was assumed that the channel is perfectly known at the receiver. However, in practice it is undesirable to spend too much time estimating the channel coefficients because this would reduce the spectral efficiency (i.e. long training sequences are not allowed, as it may be impractical to estimate them within an acceptable delay constraint). Also, the assumption of perfect knowledge of the channel state information (CSI) may not be realistic with a large number of transmit antennas. Therefore we analyzed in [2] the impact of imperfect CSI on the decision metric of the Viterbi algorithm (VA) and on the performance of this scheme.

We also developed a novel receiver scheme that uses pilot symbols to estimate the channel coefficients and couples this with an iterative process that uses the decoded information to improve the initial estimates. In order not to reduce the spectral efficiency of the system too much, we used a minimal number of pilot symbols for the initial channel estimation. In addition to this, we compared our scheme with other schemes. It was shown through simulations that the absolute channel estimation error at high signal-to–noise ratios (SNRs) for our scheme is equal to that of a system in which only pilot signals are transmitted. At low SNRs the performance of the channel estimation scheme is not further improved by the iterative decoding and channel estimation process. We also showed in [2] that our scheme performs better than other schemes with higher complexity. In conclusion, the WSTC in [1] gives good performance at low complexity. However, the performance strongly depends on the accuracy of channel state information at the receiver. Our new receiver scheme reduces the effect of channel estimation errors on the frame error rate through joint decoding and channel estimation.

This work was supported in part by the German Ministry of Education and Research (BMBF) under grant 01BU150.

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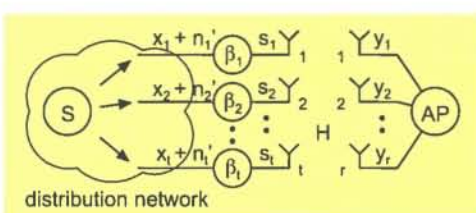
On a Distributed Multiantenna System using Cooperating Transmitters

We examine a system in which a station desiring transmission cooperates with other reachable stations in its vicinity to achieve a performance gain from the resulting distributed multiple antenna link. Here we consider the cooperative concept of amplify and forward, in which the cooperating stations amplify and retransmit the received signal. An example of an optimal power allocation strategy for improved capacity is presented.

Future radio systems will make use of cooperative concepts between independent transmitters and receivers to increase the coverage area and data rate and/or to decrease the power consumption of the wireless communication network.

Figure 1 shows the underlying model of the distributed multiantenna system under consideration.



A station wishing to transmit, depicted by the information source S, divides its information into t independent signals x_i of equal power and distributes them through an unspecified distribution network to the cooperating stations CS. Each signal is disturbed by an additive white Gaussian noise n_i, also assumed of equal power. Each cooperating station amplifies its disturbed signal by the factor β_i and transmits the amplified signal s_i to the access point AP, at which the signals from each of r antenna elements are further disturbed by additive white Gaussian noises of equal power. This model may for example represent a situation in a WLAN in which a station wishing to transmit data does not have an adequate link to an access point.

In [1] we calculate the system capacity. Obviously the capacity depends on the chosen amplification factors of the cooperating stations, which also determine the corresponding transmission powers. It is shown that the capacity converges to a limit, determined by the noise of the distribution network, as the power of the cooperating stations increases.

There is great interest in finding the optimal amplification factors that maximize the system capacity, constrained by the maximum total transmission power of all cooperating transmitters. This leads to a non-convex optimization problem with affine inequality constraints. A closed form solution can be derived in the case t = 2 [1]. In other cases it can be solved by a numerical algorithm. The results give deeper insights into cooperative transmitter systems.

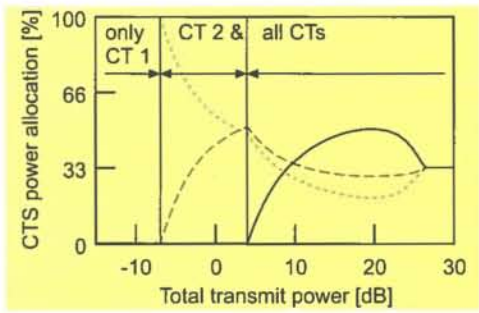


Fig. 2:
Example of an optimal power allocation of a system with $t = r = 3$ and arbitrary channel realisation

Fig. 1:
System model

The optimal number of cooperating stations depends on the total transmission power. Accordingly, the optimal power allocation between the cooperative stations may be likened to the waterfilling strategy in MIMO systems, although no unitary preprocessing takes place.

This result is of practical importance, since it gives the optimum number of stations to allocate for a given total transmission power in a particular scenario. Hence it suggests design constraints for the unspecified distribution network.

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QS-CDMA versus W-CMDA: A Comparison of Air Interfaces for Wireless Communications

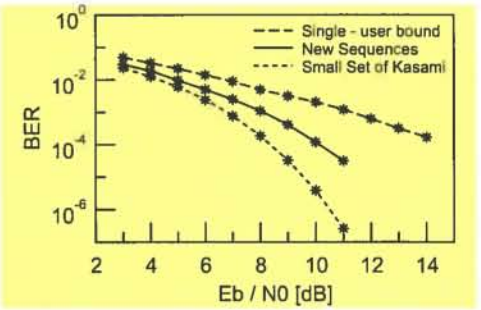
Sequence design for W-CDMA (wideband code-division multiple access) is difficult, making the use of scrambling codes necessary, which drastically decreases the channel capacity. In contrast, good sequences for quasi-synchronous CDMA (QS-CDMA) systems are known and can be used to enhance the system performance.

The decision to use CDMA as a multiple access scheme for UMTS (Universal Mobile Telecommunications System) was made because of its enormous potential for large spectral efficiency. CDMA can achieve spectral efficiency improvements by incorporating a number of features. Chief among these are frequency reuse, soft capacity, soft handover and mitigation of the effects of faded transmission through the use of a RAKE receiver.

As UMTS is being implemented, it is becoming obvious that W-CDMA may not fulfil all its expectations. For instance, it is difficult to satisfy stringent quality of service requirements with regard to data rate and loss. This is especially true in the uplink channel, in which random signature sequences are used for the channelization of users. The use of random sequences results in strong multiple access interference, making reliable, high data rate communications impossible. The main reason for such an approach is that sequence design for fully asynchronous CDMA systems is a notoriously difficult problem, and no systematic methods are available. The situation is further complicated by the fact that variable spreading factors are employed to support variable data rates.

In QS-CDMA, users are approximately synchronized, in the sense that the maximal signal delay (relative to a common clock) is significantly smaller than the duration of the signature waveforms. Furthermore, all signature sequences used in QS-CDMA have the same length, and variable data rates are supported through the use of multicode spreading techniques. In many practical situations coarse synchronization is either already given or can easily be established [1]. This fact can be used to improve the system performance, provided that the aperiodic correlations of the signature sequences are optimized in a certain window around the zero shift, the so-called interference window.

In [2] we proposed criteria for selecting signature sequences for QS-CDMA systems and derived lower bounds on them. The bounds suggest an enormous potential for performance gain. We presented two methods for the construction and allocation of signature sequences. In some cases the correlation parameters of these sequences are close to the optimum, showing that the design of good sequence sets for QS-CDMA is a feasible problem.



Average bit error rate in a multipath QS-CDMA channel with 8 users and with processing gain 63.

The figure depicts the average bit error rate as a function of the signal-to-interference ratio in a multipath QS-CDMA system. We compared new sequences with the well-known Kasami sequences, which are optimal with respect to the maximum periodic correlation value. The simulation indicates that we can improve the performance by as much as 4 dB at a bit error rate of 10^{-4}.

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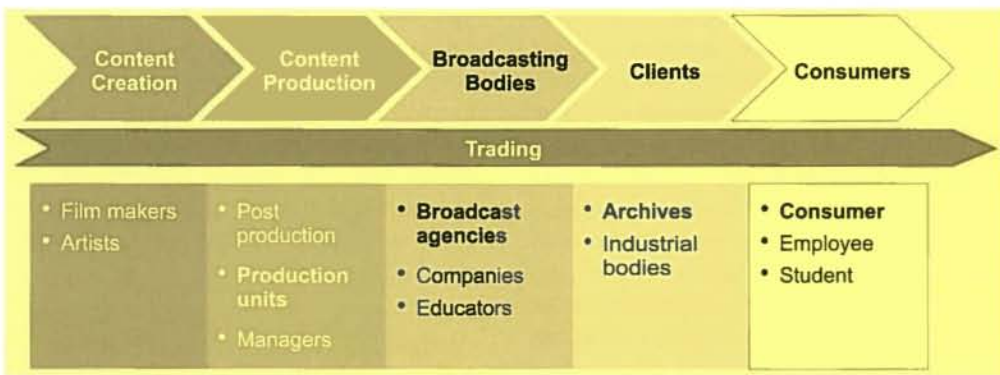
User-Friendly Retrieval of Video Content from Large Databases

When designing a system for efficient retrieval of video content from large databases, various factors have to be taken into account, among others the large variety of content and many different user requirements and reasons for using the system. In the BUSMAN project both of these issues are addressed by embedding relevant and fully MPEG-7 compliant metadata into the video content. Based on interviews with potential users, those descriptors and description schemes that best fit user expectations and demands for successful video retrieval were selected and have been implemented into a metadata model.



The value chain, with the stages addressed by BUSMAN shown in bold

MPEG-7 offers a wide range of possible descriptions of video content that allow direct access to individual video files or video segments, as well as links to related material of any kind. From a user's perspective, not all of them are relevant for all purposes or for all video content types.

Following the value chain shown in the figure, the users addressed in the BUSMAN project might be roughly classified as private users (consumers) and professional users (production units, broadcast agencies and archives). The video content chosen are movies, sports footage material (football), and tourism video material.

BUSMAN adopts a user-centred approach, as suggested in ISO 13407. The video retrieval requirements of various user groups were derived from interviews and focus groups conducted by the BUSMAN consortium.

Across the very heterogeneous groups the results show a strong requirement for querying using high level descriptions of the video content, such as creation information (e.g. actor, director), classification (e.g. genre) and semantics (events, objects), rather than low level descriptions such as colour, shapes or textures.

The main requirement reported from the professional group is the demand for fast access to high quality non-degraded video. Free text search with the possibility of iterating the search is needed. For instance, the light conditions of shots are of great interest. These aspects can be covered by applying relevance feedback approaches in order to find similar keyframes.

Since the annotation of video material is a time consuming process, an effective annotation tool is required to embed the relevant metadata. The development of mechanisms that allow high level descriptions to be inferred from low level information is being considered. These should be at least semi-automatic.

Querying and delivery across mobile environments based on GPRS, UMTS, fast fixed networks and the Internet is also being considered. Because of the special characteristics of the various networks and devices, a number of constraints on the input and output facilities must be taken into account. In particular, the mobile access to video databases requires user interfaces that allow a straightforward navigation by means of menu structures that meet user's expectations. The search interests reported by private consumers seem to allow a hierarchically organised search.

This work is partly funded by the European Commission under the European Union's Information Societies Technology Programme (IST).

Further information on the BUSMAN project can be found at http://www.ist-busman.org.

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User-Tracking 3D Display for 3D TV and Internet Browsing

The availability of 3D displays is essential for the introduction of 3D TV and PC-based systems implementing augmented reality. This article describes a new type of tracked single-user display suitable for 3D TV and internet browsing.

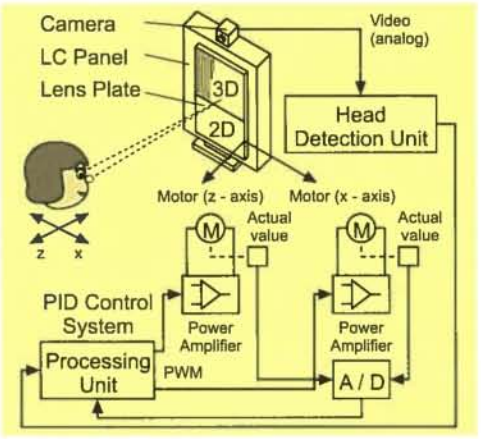
At present, a glasses-free 3D display that enables free positioning of the viewer is not available. Most of the existing 3D displays impose fixed viewing positions. Others include a limited form of head tracking to provide a multitude of fixed positions for good 3D viewing, but in between these viewing zones an acceptable 3D impression cannot be generated. HHI is currently developing a display that will allow free positioning of a single viewer within a 60 degree angle. A second common artefact of currently available displays is crosstalk between the left and right views. The optics for the new development will be designed so that extremely low crosstalk (< 1 %) and excellent colour reproduction will be achieved.

For the representation of stereoscopic content, two partial images showing an object or a scene from two slightly different perspectives must be presented at the same time. A technology patented by the Heinrich-Hertz-Institut [1] guarantees a correct optical addressing of the user's eyes. Left and right images are split into vertical stripes which are steered on the appropriate eyes by means of fine cylindrical lenses. Depending on the viewer's displacement, a lens plate is tracked in two axes with a precision of about 10 µm. A special bearing setup and a driving device using voice coil motors enables the viewer to perform lateral and frontal movements while watching excellent stereoscopic video images. In addition to low cost, voice coil motors have other advantages in this application, including especially noiseless operation, high velocity and accuracy, and manageable driving electronics.

Technical design of the 3D display

The screen of a 21'' liquid crystal panel is split into monoscopic and stereoscopic display areas. While 3D images or movies are being displayed in one area, the second display area can be used for monoscopic presentations, such as additional program information for 3D TV or an internet browser for searching 3D content.

The detailed technical design of the tracking 3D display is shown in the figure. A robust camera-based head detection device was developed to sense the head position without any user-worn devices such as glasses. An optional infrared light source ensures optimal eye detection even if the existing visible illumination is insufficient. The patterns of the captured images are analysed via a PC-based frame grabber system to detect the eyes of the observer. The processed head location data are sent to a processing unit which supplies a pulse-width modulated data stream for driving several voice coil motors – one for the lateral axis and four for the frontal axis. The required performance and precision of the real-time spatial positioning of the lens plate is achieved using a custom-made PID control system.



Human factors studies at all stages of the development will determine the user requirements for optimal 3D visual enjoyment. They will also provide tools for quality control during the development.

This work is supported by the Information Society Technologies Programme (IST) under the Fifth European Community Framework Programme.

[1] R. Börner, "Autostereoscopic viewing device for creating three-dimensional perception of images", Patent applications EP 0 404 289 B1, US 5,083,1999, and P 2.874.966.

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A New Similarity Measure for Segmented Images

A new similarity measure for segmented images was developed. This measure takes account of the colour, edge, texture and shape properties of image segments as well as their relative positions.

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

Feature vectors describing visual properties such as colour, texture and edge statistics are computed for the whole image. Images are considered to be similar if the Euclidean distance between their feature vectors is small. Figure 1 shows the result of such a search request.

Retrieval is fast with this method, but the retrieval results are not satisfactory – there may be retrieved images with no similarity to the query image.

The typical user searches for images showing semantic objects such as cars, houses or persons. These semantic objects cannot be described by feature vectors calculated from the whole image. An adequate description needs both a suitable representation of the visual properties of the individual image segments and their positions relative to each other.

In our research a new graph-based similarity measure for comparing whole images and parts of segmented images has been developed. It takes account of the colour, edge and textural properties of image segments as well as their relative positions. Hence the user can search for semantic objects.

The transformation of an image into a labelled graph requires two steps. Image segmentation and the extraction of MPEG-7 descriptors, which describe the visual properties, take place in the first step. In the second step the images are represented by labelled graphs. The set of all centroids is the set of nodes. Every node is labelled with an MPEG-7 feature vector. Edges are introduced between each pair of nodes. The edges are labelled with the distances between the centroids, normalized with respect to the image diagonal.

Images are considered to be similar if the distance between their representations by a configuration of features is small. Due to the graph representation used here it is necessary to compute a graph distance. Most graph distances need a unique node assignment. But there is still no system that is able to automatically segment images into semantically meaningful parts. Furthermore the segmentation results depend strongly on the illumination condition, camera position and algorithm parameters. Different graph representations of one and the same image are possible.

In order to compare two images, both graphs are first normalized. This is necessary to handle the segmentation dependency. We formulated the graph normalization problem as an optimization problem and solved it using a connectionistic method. The normalized graphs are then used as the basis of a fast recognition procedure, using a special neural net to compute the graph distance. This graph metric is described in the HHI Report 2001. For more details see [1] and [2].

Fig. 1:
Result of a classical search request. The complete first image is the query image.

Fig. 2:
Result of a search request using our approach. The framed image part is the query image, and the underlying labelled graph is the query graph.

[1] S. Bischoff and F. Wysotzki, "Graph based representation of objects in image retrieval", Proc. 5th International Workshop on Internet Technology and Applications, Kluwer Academic Publishers, 2002.

[2] S. Bischoff and F. Wysotzki, "A new distance measure for segmented images based on MPEG-7 descriptors", Tech. Report 2019, TU Berlin, Germany, 2002.

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Mobile Services for Citizens

One of the potential benefits of mobile e-government is "to take the services to the citizens", instead of expecting citizens to go to the services. The project "mobile citizen services" aims to offer a broad range of services (passports, wage tax cards, driving licenses, etc.) by means of a mobile one-stop office for citizen services. The office is being developed and tested jointly with a software company. Various local administrations in the city of Berlin are the pilot users.

Many communities and offices of citizen services are presently trying to improve the relationships between administrations and citizens. One step in that direction is to organize offices of citizen services – which are mainly located in town halls or similar buildings – as one-stop offices in which citizens can be advised and can use services from a wide range of different public administrations.

Consultancy in an office of citizen services

As a second step, some administrations have started to offer access to some citizen services over the Internet, e.g. for downloading forms or even for filling in electronic forms.

However, these innovations do not adequately cater for citizens who are, for various reasons, not able or not willing to use the offices of citizen services. For example, for elderly, ill or disabled citizens it is very often too exhausting to walk or ride to a public building. Sometimes they can only make use of citizen services by means of a substitute. Similarly, use of the Internet requires suitable equipment and a certain experience in using software such as Web browsers etc.

In view of this, the project "mobile citizen services" is researching novel possibilities for offering citizen services at different and changing locations by exploiting mobile/wireless networks and terminals. In particular, the project aims to develop and test a mobile office of citizen services that can offer a wide range of services, including registration, passports, driving licenses, wage tax cards, social benefits, etc.

These mobile offices should support the entire work flow, from consultancy through application and payment to the final delivery of (hard) documents to the citizen.

They will be present from time to time in residential homes for the elderly, perhaps hospitals, but also in shopping malls or at weekly markets.

Besides being more citizen-friendly, those mobile (or "nomadic") offices are expected to be more efficient, as they do not require such high rental fees and maintenance costs as stationary offices. Especially in large administrative districts they will offer a new quality of public service by "taking the office/service to the citizen".

The project consortium consists of the HHI as a research institute, a software company, and two administrative districts of the city of Berlin as pilot users. HHI is responsible, among other things, for the user requirements analysis, the data collection and analysis during the field trial, and the usability design of services and terminals.

The use of UMTS is envisaged at a later state of the project, but at the beginning GPRS and WLANs will be used for wireless data transmission.

The project has started by analysing the organisational, legal, technical, and ergonomic requirements, among other things, for a mobile office of citizen services by visiting stationary offices and conducting first interviews with experts in the field. In addition, a first version of a software system for various citizen services was made available on a mobile notebook via a WLAN.

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Innovative Man-Machine Interfaces

Starting from technological trends in the field of information and communication technology, a study was done to help find the requirements for innovative man-machine interfaces and to predict the challenges to be met in future hardware and software development projects.

The present study was performed by a consortium of eight Fraunhofer organisations, namely ESK München, FIT Sankt Augustin, HHI Berlin, IGD Rostock, IIS-A Erlangen, IMS Dresden, IZM Berlin, VμE Berlin, and the centre of the Fraunhofer Microelelectronics Alliance (VμE).

The objective of the study was to develop a framework to help decide what requirements should be satisfied by innovative man-machine interfaces and what challenges are likely to arise in future hardware and software development projects.

The study was motivated particularly by the fact that existing man-machine interfaces are not adapted to a technological evolution that is characterized by the following trends:

- The convergence of language, multimedia data and services.
- The expansion of functionality and services in the areas of information, communication and action possibilities in all life fields.
- The increased support of users by electronic assistants and "smart objects".
- The availability of the entire spectrum of functionality and services at every time and at every place (ubiquitous computing).

The state of science and technology in the fields of microelectronics, software engineering and usability of services and terminals was surveyed and analysed in the study.

The task of the HHI was to identify challenges and solutions for usability problems that result from:

- The transition from stationary internet applications to mobile applications.
- The miniaturisation of input and output facilities.
- Reduced bandwidth when using mobile devices.

The outcomes of the study were presented during a workshop in October 2002 and are described in the final internal FhG report in December 2002. To illustrate the type of results obtained two examples are given:

(1) To solve the problem that results from the miniaturisation of mobile devices, it is proposed to develop virtual image displays that deliver a range of vision similar to that of the usual PC monitors.

(2) A severe usability problem arises because of inconsistencies between mobile user interfaces that were developed for different contexts and different applications. An approach to cope with this problem is proposed.

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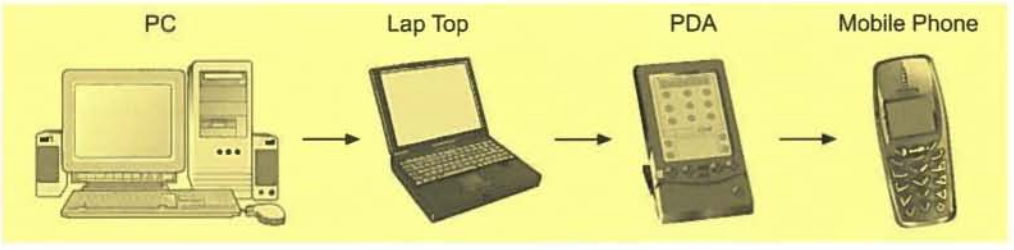

Technological trends that require new man-machine interfaces

Hybrid Display – Towards Natural Interaction in Mixed Reality

The Hybrid Display embeds a unique autostereoscopic 3D display into a surrounding 2D display area. With a simple hand gesture, the user may drag a virtual object from the 2D area and drop it into the 3D display, where it seamlessly merges into the real desktop environment. In contrast to current stereoscopic techniques, there is no accommodation conflict when the user attempts to touch and manipulate a virtual object floating over the desktop with the hand or a real tool.

Human stereoscopic vision is limited to a central binocular region where the visual fields of the left and right eye overlap. The binocular field extends about 114 degrees. It is flanked by two monocular sectors within which objects are visible to only one eye. In the lateral sectors, spatial vision relies on monocular depth cues such as shading, perspective and occlusion.

From this fundamental concept of human vision, we have derived the idea of the Hybrid Display. With the Hybrid Display the 3D presentation is confined to the central part of a wide-screen display, while the area surrounding the 3D image reproduces only monocular depth cues. Since the entire display area belongs to a joint data space, it is possible to make the 3D imagery merge seamlessly into the surrounding 2D region.

We have implemented this concept in a fully operational prototype. Unlike conventional 3D techniques, the central 3D display creates a stereo image pair focused on an aerial image plane floating 20 cm in front of the display [1]. Stereo glasses are not required. The prototype display provides a symmetrical 3D stereo resolution of 2 x 1024 x 768 RGB pixels, and each of the 2D panels immediately adjacent to the 3D area adds 1280 x 1024 pixels to the usable screen space.

The novel display is very comfortable to use (no eye-strain), since it allows accommodation (focal adjustment of the eye lens) to the virtual object's stereoscopic distance. By contrast, conventional 3D displays are known to produce conflicting accommodation stimuli when users try to directly touch 3D objects appearing stereoscopically in front of the display [2].

The floating image produced by the 3D display looks like a hologram (very high contrast and brightness, no crosstalk, high resolution) hovering over the desk. The user may touch it like a real object. Hand gestures are recognized remotely by a video-based stereo hand tracker embedded in the desk in front of the display. Optionally, tactile feedback when touching a virtual object is provided by a force-feedback device. Within the 3D area there is perfect correspondence between the visual and tactile spaces.

Natural interactions with virtual objects become possible with this display. With a simple hand gesture, the user can pull a computer-generated object out of the 2D area and move it into the 3D area (drag and drop), where it will float like a holographic image within reach over the desk. Since the accommodation distance of the virtual object equals the distance of the real thing used for manipulation (hand or end effector of a force-feedback device), there is no accommodation conflict. Hence this display is ideally suited for mixed reality interaction, for example, in construction applications, medical applications (diagnosis, surgery planning) and chemical applications (molecular design).

Prototype of the desktop Hybrid Display for mixed-reality interaction (as shown at the CeBIT 2002)

This work was supported by the Federal Ministry of Education and Research under grant 01 BD 250.

[1] S. Pastoor and J. Liu, "3-D display and interaction technologies for desktop computing", in: B. Javidi, F. Okano (eds.), Three-Dimensional Television, Video, and Display Technologies, Springer Verlag Berlin, 2002, pp. 315-356.

[2] S. Pastoor, "3D-Displays: Methoden und Stand der Technik", Handbuch der Telekommunikation, vol. 4, 12.2.1.0, 89, Deutscher Wirtschaftsdienst Köln, 2002, pp. 1-51.

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Inside-Out Optical Tracking for Mixed-Reality PDAs

Mixed reality interfaces (MRIs) overlay three-dimensional graphical objects on live video and allow interactions between real and virtual objects. The use of optical methods to track natural features in real time enhances the use of MRI in mobile platforms such as PDAs and Tablet PCs, thus opening a whole new raft of applications in real environments.

Mixed Reality Interfaces integrate dynamically generated 3D objects into a physical 3D space in real time. They can be used to navigate, manage and visualise information resources and to control tasks. Accurate registration between real and virtual objects is crucial for MRI because the objects in the real and virtual worlds must be properly aligned to avoid unnatural perceptual artefacts. Although registration based on magnetic and ultrasonic sensors has been reported, optical tracking has advantages. It uses the very same image for the registration as the image on which the synthetic objects will be superimposed and it doesn't suffer from workspace limitations.

Techniques supporting inside-out optical tracking (tracking the pose of the camera) based on natural features are exploited and implemented in a prototype system that was developed for the purpose of demonstration, case study, and user evaluation in the project "Mixed3D". To keep the hardware requirements low (bearing in mind applications in mobile platforms), the current version of the MRI prototype is based on a monocular video system that avoids synchronization problems between different cameras. It is implemented as a coder/encoder structure to provide, as far as possible, application independency and flexibility.

The coder part consists mainly of the registration framework that computes the pose of the camera as the PDA moves. This framework is based on a coarse-to-fine model-based approach. In the initialization stage, having a model of the object, a video image is analyzed and features belonging to a plane are extracted. The plane projective transformation (homography) is computed and decomposed to provide a first estimate of the three dimensional position and orientation of the object. In the tracking stage the current pose estimate is used to initialize an iterative pose estimation process based on the Gauss-Newton algorithm. This is computationally very efficient, and also allows the recovery of internal degrees of freedom (e.g. an object with a rotational part) and the tracking of focal length variations (e.g. lenses with auto-zoom features).

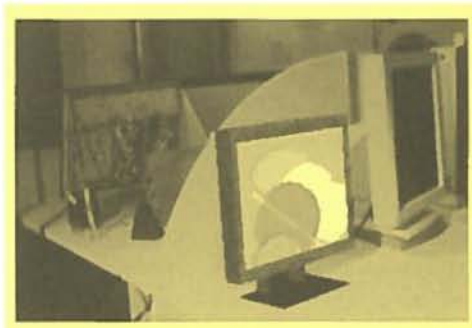

Fig. 1:
View of the dynamically generated object superimposed onto the live video image

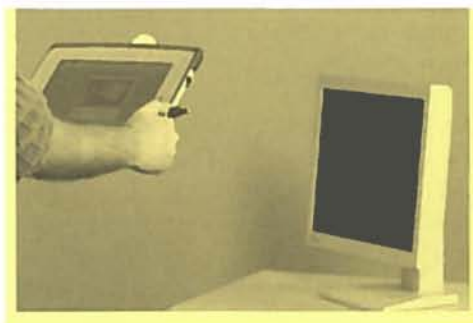

Fig. 2:
View of the mobile MRI prototype

A visualization framework based on DirectX is the core of the encoder. It takes care of object generation, rendering and shadowing of the virtual objects. For the dynamic object generation a model of the object and a virtual camera are used. The virtual camera has the same optical properties as the physical one and it is used to project the model according to the pose provided by the coder. The synthesized image is then superimposed onto the live video image.

At present the MRI runs at 20 Hz on a Pentium IV system at half PAL resolution. The goal in the future is to integrate the MRI into a 3D PDA and to extend the existing prototype so that it is robust to outliers, handles object occlusion, and merges different kinds of features and various pose recovery strategies.

This work is supported by the Federal Ministry of Education and Research under grant 01 BD 250.

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Low-Cost Video Head Tracker for PC Applications

So far head tracking devices have been used only for special applications running on high-end workstations. This situation has changed with the increasing processing power of PCs and the availability of inexpensive web cameras. It is now possible to use a head tracker as an input device for any general-purpose PC. "Head mouse" and dynamic perspective are typical applications for low-cost video head trackers.

Computers are increasingly used outside the office, for example in car repair workshops, chemical laboratories and production plants. Typically, in such environments the user's hands are not free for interaction or there is simply too much dirt for using standard input devices such as keyboards, joysticks or mice. A remote (video-based) head tracker is perfectly suited for hands-free cursor positioning and menu selection in such applications.

A video head tracker can also be used to control other devices, such as the vantage point of a camera in surveillance and inspection tasks and the orientation of a display. When used with a 3D display, a head tracker can couple the rendered view to the user's head movement (dynamic perspective), thereby providing a very natural look-around effect. In addition, most of the emerging autostereoscopic 3D displays (i.e. 3D without stereo glasses) require a remote head tracking device to optically address the observer's eyes.

In our earlier approaches to video-based head tracking we used high-end capturing devices (precision miniature cameras and PCI frame grabber boards) in order to achieve maximal robustness, precision and adaptability as well as minimal measurement latencies [1]. The hardware costs were accordingly high (typically about € 1,000).

In order to address an extended application market, we have completely redesigned our software and modified the basic algorithms. The new head tracker accepts a wide range of video cameras and camera interfaces, including web cams (320 * 240 pixels at 30 Hz) and special high speed cameras (648 x 247 pixels at 120 Hz). Also, with a software redesign we were able to reduce the processor load significantly. The recent software version uses less than 20 % of the CPU power, so that other applications may run (and be controlled by the tracker) on the same PC without delay.

Most computer vision algorithms require high-quality video inputs and full knowledge and control of the camera parameters. On the other hand, with typical low-cost web cameras the automatic gain control mechanism cannot be switched off and the image quality is far from excellent because of compression and lens artefacts. Moreover, current USB web cams have a substantial latency. Because of the frame-interleaved compression, about 160 ms elapses before a recorded image is available to the head-tracker image processing algorithms. Such a delay can only partly be compensated by the predictor implemented in our software (a predictor is typically very sensitive to noise interference). However, first trials show that even with the existing latencies the tracker can be used to reasonably substitute for a mouse and to provide a dynamic perspective.

Graphic user interface of the video head tracker, showing a sample application with dynamic perspective. The web cam used is easily mounted on top of a monitor.

Projected USB 2.0 and IEEE1394 cameras work without video compression. This will significantly reduce the latency, so that the low-cost head tracker can then be used in delay-sensitive applications as well.

This work was supported by the Federal Ministry of Education and Research under grant 01 BD 250.

[1] S. Pastoor and J. Liu, "3-D display and interaction technologies for desktop computing", in: B. Javidi, F. Okano (eds.), Three-Dimensional Television, Video, and Display Technologies, Springer Verlag Berlin, 2002, pp. 315-356.

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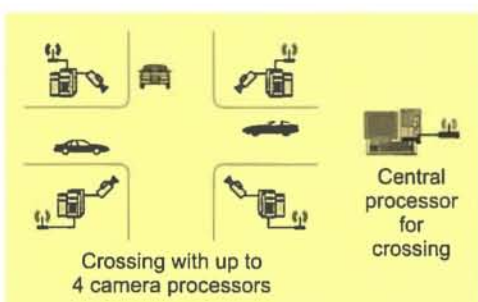
Multiple View Traffic Surveillance with 3D Scene Reconstruction

Visual surveillance systems have become very common and accepted in modern society. An important special case is traffic surveillance, where for instance a crossing is observed by a number of cameras. A system for multiple view traffic surveillance has been developed, including several remotely controllable video servers and a multi-client. We also present further advanced functionalities that can be provided if multiple views of a traffic scene are available. A complete interactive 3D model of the scene is constructed.

The development of algorithms and formats for interactive multiple view video systems has become an important field of R&D. The project OIS targets a traffic surveillance scenario in which a crossing is observed by a number of cameras (typically four).



Scenario for multiple view traffic surveillance and video streaming using a WLAN

The first part of this work is about a system that is suitable for video capturing, encoding, transmission and display. A remotely configurable video streaming server has been developed, capable of video capturing, format conversion, MPEG-4 encoding and RTP streaming. The server can be controlled via a special TCP interface from a central client, in order to adjust to varying network (e.g. WLAN) conditions and user requirements. This is done by adjusting format conversion and encoder parameters.

A multi-client is being developed as a control station. It displays the traffic surveillance videos of the cameras in the network, controls the dynamic transmission system (it measures network conditions and configures multiple servers accordingly), and handles the user interaction. For example, it is possible to switch views on and off and to get enlarged views from selected cameras.

The second part of the project targets 3D scene reconstruction and a system for interactive navigation within the extracted 3D model. For this purpose the scene is divided into static and dynamic parts.

The static parts are handled off-line and interactively. This includes calibration of all cameras, background extraction in all views and 3D background modelling as multi-textured objects (surface light fields). The textures are derived from the different camera views. The static models can be updated, e.g. if there is a change of lighting.

The dynamic parts of the scene are vehicles, pedestrians and others. These are handled on-line and automatically, including segmentation of all views, multiple view tracking and 3D reconstruction. The last is done by selection and adjustment of an appropriate 3D model from a data base, with texture mapping from the original video sequences.

The modelled static and dynamic scene elements are combined in a 3D scene representation which is realized in DirectX and can be viewed and navigated interactively. The dynamic traffic scene can be viewed from an arbitrary position.

The technology developed in OIS is not restricted to the traffic surveillance scenario. The transmission system could also be used for other purposes, e.g. for video conferencing with several persons. The 3D scene reconstruction system could be used for a variety of similar scenes and camera settings.

These developed and other similar technologies for video based rendering have received much interest in recent years. They have in common that they support interactivity with the content, in that the user can select his or her own view direction and/or viewpoint in an audio-visual scene (within a certain operating range). Therefore MPEG has started to investigate the need for standardization in this field in a new initiative, which is called 3DAV. HHI has been very active in 3DAV from the very beginning and has contributed many inputs, e.g. for interactive stereo and omni-directional video.

This work was supported by the Federal Ministry of Education and Research under grant 03WKJ02C.

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An MPEG-4 Video Codec ASIC for Mobile Applications

Mobile multimedia is predicted to be one the major applications for future broadband mobile networks such as UMTS. As well as pure streaming applications for unidirectional communication, bidirectional applications such as video teleconferencing and multimedia messaging will become increasingly popular.

MPEG-4 defines compression schemes for audio and video streams at a wide range of channel data rates. Therefore it has also been adopted for the next generation of visual communication systems for mobile environments such as 3GPP. The variety of implementations of MPEG-4 systems range from pure software solutions to application-specific processor systems. Pure software solutions require large processing power and are therefore mainly restricted to run on PCs. Application-specific processors allow a hardware-efficient implementation and are therefore the choice for compact and power-sensitive solutions, as required for example in mobile applications.

In the figure the overall architecture of the complete MPEG-4 Simple Profile video codec is shown. This has been implemented in cooperation with a German IP company.

Based on a hardware-software partitioning, parts of the video codec algorithm are mapped onto a programmable processor while others are mapped to dedicated hardware modules.

The video input module (M4VI) comprises a camera interface, and also scalers in the general case. The video output unit provides picture scaling and colour conversion, an on-screen display (OSD) unit and an LCD interface. A motion estimation module (M4ME) can be used to avoid the computationally intensive calculation of motion vectors by the processor. A similar option holds for the post-filter task, for which a video enhancer module (M4VENH) is provided. The data flow is controlled by interrupts, which are processed by an interrupt control unit. A common SRAM is used for the exchange of data between the processor and the various hardware modules.

The main advantage of the proposed system architecture, which is based on dedicated hardware accelerators, is the large reduction of the load on the main processor.

Another major advantage of this architecture is the very low power consumption, which is mainly due to the hardware accelerators. They greatly lower the processor load in comparison to a pure software solution. The power consumption is lowered further by several power-down modes.

A more detailed description of the MPEG-4 codec can be found in [1].

[1] B. Stabernack, M. Köhler, M. Reißmann, G. von Cölln, "A processor based system on a chip design for mobile multi media applications", IEEE International Symposium on Consumer Electronics ICE 02, TU-Ilmenau, Germany, 24-26 September 2002.

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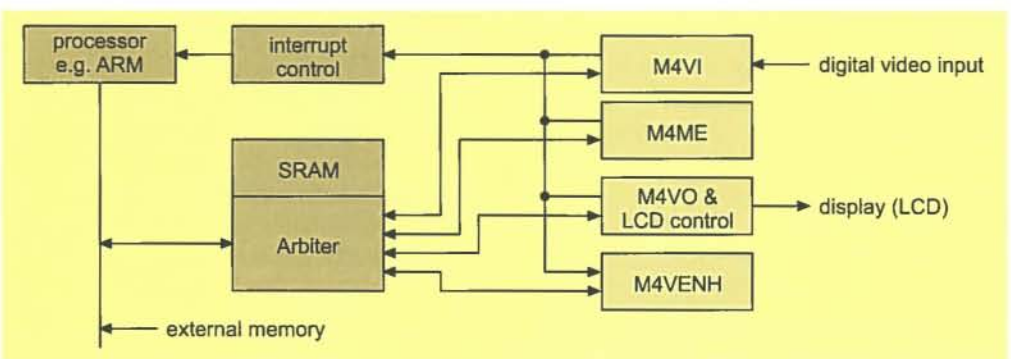


Block diagram of the MPEG-4 video codec

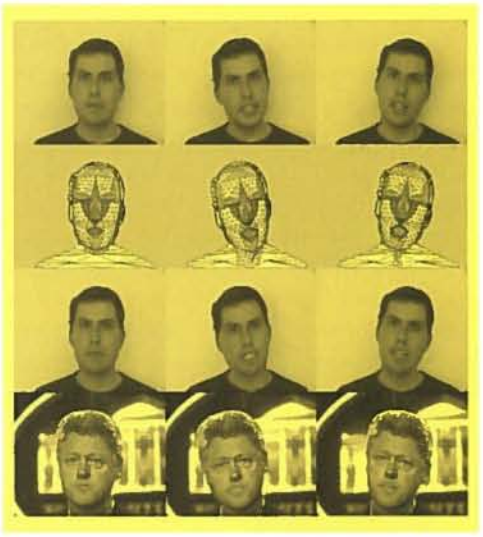
3D Model-Based Coding of Video using MPEG-4

A new system for the encoding of head-and-shoulder video sequences at bit rates of a few kilobits per second is presented. 3D computer models are used to represent the person in the scene and MPEG-4 animation parameters are used to define temporal changes of facial expressions. Extremely low bit rates and simple access to the semantic information enable a wide variety of new applications.

In recent years several video coding standards such as H.261/3 and MPEG-1/2 have been introduced. These mainly address the compression of generic video data for digital storage and communication services. These schemes, including the future standard H.264, are designed on the basis of the statistics of the video signal without knowledge of the semantic content. By contrast, model-based codecs [1] are based on the semantics of the scene. Higher coding efficiency can be achieved by using 3D computer models to represent the objects in the scene. For the typical class of head-and-shoulder scenes frequently found in applications such as video-telephony or video-conferencing systems, bit rates of 1 kbit/s with acceptable quality have been reported [1].

In a model-based codec a generic 3D head model specifying the shape and colour of the person in the video is adapted to the individual. The texture and geometry of the face object are encoded only once and transmitted to the decoder. Subsequently, 3D motion and the facial expressions of the person are estimated from each frame of the image sequence. A set of facial animation parameters (FAPs) defines, together with the head model, the current appearance of the person. The MPEG-4 standard [2] defines such a parameter set and allows standard-compliant facial animation. The parameter set is then encoded and streamed over the network. At the decoder, the 3D head model is deformed according to the FAPs and new frames are synthesized using computer graphics techniques.

Although decoding of FAPs and animation of 3D head models for model-based coding are standardized in MPEG-4, no information is provided in the standard about how to determine the FAPs from an image at the encoder, and satisfying model-based coding systems are still very rare. At the HHI a new model-based coding system using MPEG-4 has been developed that targets high quality encoding of head-and-shoulder scenes at bit rates of a few kilobits per second. New methods have been developed to robustly estimate the 3D motion and deformation parameters from monocular image sequences.



Original sequence

Animated wireframe model

Decoded frames

Animation of arbitrary people

The figure illustrates the quality of the codec. The first row shows the original sequence while the second row shows the animated wireframe model. Texture mapping generates natural-looking synthetic frames, as shown by the decoder output in the third row. As well as leading to an extremely low bit rate, which allows the transmission of video streams even over low-bandwidth wireless channels, the semantic representation simplifies interaction with and modification of the scene content. For example, in the last row of the figure the head model at the decoder is replaced by that of a different person, which enables new applications in character animation and film production.

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[2] ISO/IEC 14496-2, Coding of Audio-Visual Objects – Part 2: Visual (MPEG-4 Video), International Standard, doc. N3056.

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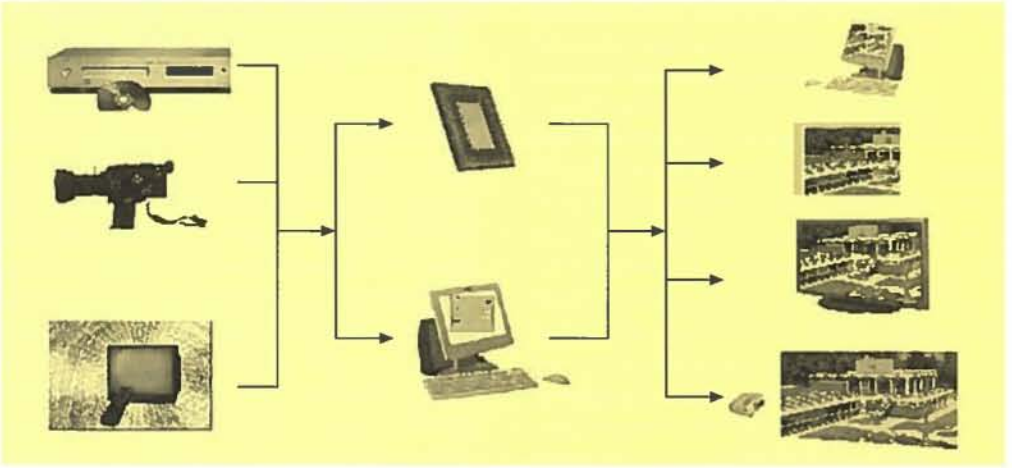
Multi-Standard Motion Compensated Image Format Converter HiCon[32]

The motion compensating image sequence converter developed in this project converts between different image sequence formats. It performs deinterlacing while preserving full spatial resolution. Furthermore, image rate conversion is accomplished with motion portrayal that is adequate for high quality image applications such as digital cinema. This is the basic requirement for the optimal flicker-free and judder-free driving of high-end displays.

The dynamic expansion of the multimedia market is accompanied by a demand for improved video performance. The newest trends suggest a future need for high quality reproduction of video on TV and HDTV displays as well as on desktop screens. As a consequence, the requirements for video reproduction are growing, accelerated not only at the high end, but also in the consumer market. Nevertheless, current practice is disappointing. Most TV screens and video projectors show annoying interline and screen flicker. Also, computer displays suffer from insufficient resolution of videos and show motion judder.



Conversion of video sources to output displays

Some of these problems could be reduced simply by increasing the computational power and bus bandwidth. However, some of them cannot. Problems related to the basic video standards and incompatibility with multimedia display formats cannot be overcome by operation at higher data rates or improvements in computation speed. They can only be solved by image format conversion. To answer this challenge, a high quality image converter of moderate complexity has been developed at the Heinrich-Hertz Institute. It provides the highest possible video quality without loss of resolution or motion judder.

In general, the basic motion compensation algorithm (an HHI patent) can be used to perform the conversion of any digital video and graphic standard format into any other. This allows numerous video sources to be adapted to different displays.

There are two implementations of the converter, a real-time hardware version and a non-real-time software version. The real-time implementation is designed as a simulated netlist based on the VHDL description language. It may be integrated onto a single chip or as an FPGA solution. The features are limited to HD/HD conversion.

The software implementation of the video converter HiCon[32] provides the greatest flexibility for the conversion parameters. It is easy to use and offers the customer a wide range of applications. User control is performed through a graphic user interface. It is a WIN32-based implementation, and is also portable to UNIX/LINUX. At this stage it is not real-time.

The main area of application is postproduction, where the electronic image sequences must be adapted to the final target format while preserving the highest possible picture quality. It may also be used as plug-in for editing systems or similar image processing software, or used as a standalone software tool.

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Processor Module based on StrongARM for Audio and Video Applications

System level low power modules capable of supporting MPEG-4 image compression and decompression, together with high quality sound, are indispensable for battery-powered hand-held systems. For this purpose a small module based on a StrongARM RISC processor has been developed and evaluated for various applications.

The main goal is the implementation of an MPEG-4 Simple Profile codec at QCIF resolution and a decoder at CIF resolution. At the same time the processor module must encode and decode MPEG-4 AAC (Advanced Audio Coding) stereo bit streams at high quality. This audio coding standard delivers excellent compression performance and supports sampling rates from 8 to 96 kHz. It gives high quality audio at a low bit rate (64 kbit/s per channel). The high coding efficiency of AAC is achieved by a combination of several new techniques (adaptive high resolution filter banks, temporal noise shaping, adaptive prediction, and entropy coding). These computationally expensive algorithms make it difficult to implement the encoding process for real-time applications. The algorithms and the module architecture in this development have been optimized for this purpose.

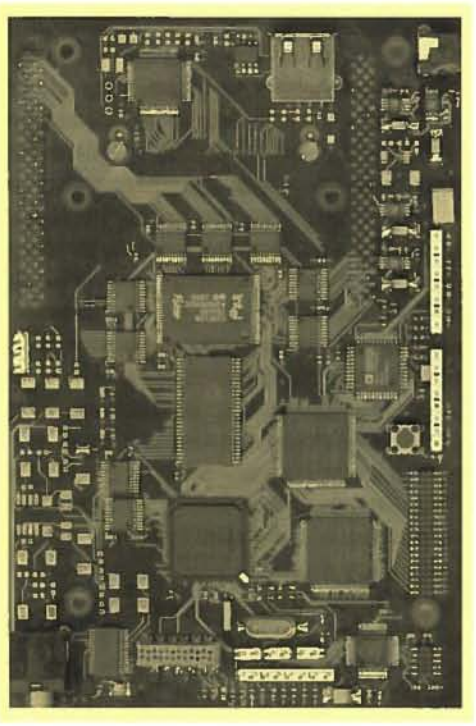
A module based on the Intel StrongARM (SA-1110) has been developed for evaluation in this application. The SA-1110 processor is optimized for portable and embedded applications. It incorporates a 32 bit StrongARM RISC processor capable of running at up to 206 MHz. It contains an MMU, an LCD controller, and serial I/O, all combined in a single component. The video processing module captures video input from a CIF source and outputs images to an LC display at a maximum rate of 30 frames per second.

The module 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.

The board that has been developed has the following resources and features:

- 32 Mbyte flash memory
- Up to 64 Mbyte SDRAM
- Ethernet 10/100 Mbit/s
- USB host and slave
- LCD display (320 x 240)
- PAL/NTSC interface
- Debug/JTAG interface
- Compact flash socket
- Input/output for analogue audio data
- Module dimensions 142 x 98 mm^2

Two inputs for analogue audio data are available: stereo LINE IN and MIC IN. A high fidelity 16 bit audio ADC/DAC converts analogue data into digital data and vice versa.



StrongARM module

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Virtual Team User Environments – a Mixed-Reality Approach to Immersive Tele-Collaboration

In the context of the European 5th framework programme IST, the project VIRTUE has now developed the first prototype of a real-time 3D videoconferencing system. In collaboration with British Telecom, Sony, Heriot-Watt University, TNO and TU Delft, HHI is a partner in VIRTUE and responsible for the real-time platform.

VIRTUE has developed new and innovative technology to produce a convincing perception of presence in a 3-way telepresence video conferencing system. The objective of the project was to create a system that allows many participants located in different geographical places to meet around a virtual table. The appearance of remote speakers is such that local participants have the impression that they are present in the same room. The purpose is to enable the participants to make use of rich communication modalities close to those used in face-to-face meetings (e.g. gestures, eye contact, realistic images, correct sound directions, etc) and to eliminate the limits of non-immersive tele-conferencing, which impoverish communication (e.g. face-only images in separate windows, unrealistic avatars, no eye contact) or skew the participants' balance (e.g. some participants appearing larger than others, or in privileged positions on screen). During the project we identified the potential as well as the limits of current technology to create such a videoconferencing system.

The final VIRTUE station

We can now present the first prototype of our system, which is developed for a three-party video-conferencing situation. A photograph of the system is seen in the figure, which shows the large plasma display, four cameras mounted around the display and loudspeakers beside it. The real table continues seamlessly into the virtual working space and the remote participants are represented in correct size and perspective. This will be achieved by very complex multi-view video processing, which consists of 3D analysis of the captured video streams and synthesis of the virtual views at the receiver side, depending on the viewer's perspective of the scene. Hence, a vision-based head tracker has been implemented. Segmentation of the remote conferees from their backgrounds is also one of the algorithm modules.

The transmission is currently realised by an MPEG-2 low delay encoder, specifically developed for the needs of this system.

In order to perform real-time processing at full CCIR601 resolution, the system is extended by dedicated hardware based on the TriMedia DSP. This hardware extension, called the VPS board (VIRTUE processor station), is based on a PCI interface and is therefore flexible and modular in terms of scalability and possible redesign of the system's architecture. All the algorithms are now able to run in real time at full resolution video, ensuring the highest possible quality of video throughout the system.

The VIRTUE consortium has developed a technology that could have a wide range of applications across a number of fields – e.g. telecommunications, broadcasting, games and engineering. In particular, the primary goal of high-realism video conferencing has been realised with a system that is expected to greatly enhance the effectiveness of communication.

This work is supported by the IST program of the EC under proposal No. IST-1999-10044.

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Standardised Software Design for Multimedia Applications

The complexity of multimedia applications has grown significantly over the past decade. Because of this, reusable, modular and well-designed software libraries must be developed to create stable, maintainable and supportable applications. This leads to cost-effective software development, protects HHI's intellectual property and reduces the time to market. This contribution describes the documented and guided software development process used in the Image Process Department to reach these goals.

In recent years, existing software design approaches have increasingly failed to fulfil the needs of large and complex software projects. At HHI a new infrastructure for software development has been established to support the following goals:

Reusability: Software has to be reusable, which means that well-designed interfaces must be provided for all components. Software must be error-free, commonly available and well documented.

Cost effectiveness: Cost effectiveness is strongly linked to reusability. Reuse of existing components allows new applications to be created in a fast and cost-effective manner, thus making software development competitive.

Protection of intellectual property: Software must be protected against unwanted access. It is desired to make software publicly available without disclosing specific know-how or giving away any rights.

Data security: Data has to be protected against technical failure. An automated back-up process that grants access to earlier versions of software releases can achieve this.

Professional documentation: Documentation must be generated by an automated process that can support various output formats and document structures (e.g. interface documentation, user manual, developer documentation).

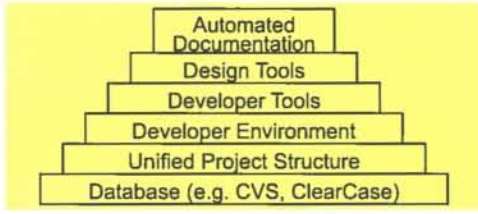
Know-How maintenance: Software must be findable, readable and understandable. This includes identification of consistent versions and automated generation of documentation.

Platform independence: Software has to be widely platform independent and needs to support multiple operating systems to increase its reusability and to decrease costs and time-to-market.

Management of complex software: The development infrastructure needs to support developer teams. A unified and documented workflow makes teamwork easier. Support and training must be provided for the developers.

Version management: Version information of files and documentation must be tracked.

To reach these goals, a small expert team has defined and established the working structure illustrated in the figure.



Working structure

This structure incorporates the following features:

A responsive database with version control and daily backup; a unified project structure ensuring proper interactivity between software modules and teams; a developer environment and integrated developer tools to create reusable, stable and portable modules; design tools (based on the UML standard) for managing large and complex software projects; active templates for automated generation of professional documentation.

The team is in charge of maintaining the technical infrastructure and providing all required developer tools. It offers training courses for beginners and advanced developers and keeps the online documentation up to date. Consulting is offered, and software synergies between various projects are detected and pointed out. Software libraries of common interest are developed, maintained and made publicly available in the database.

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A Concept for 3D TV

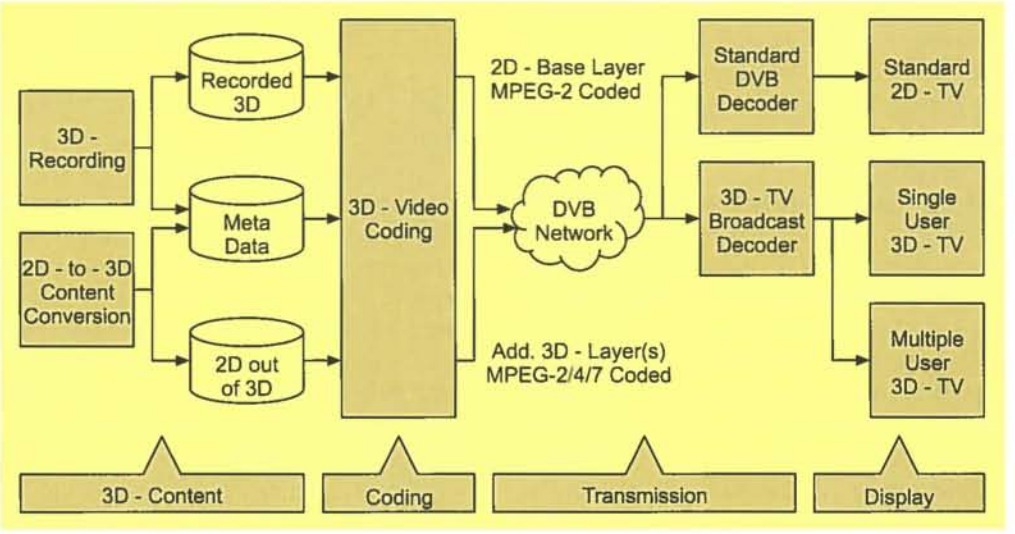
We present the concept of a novel 3D-TV system that allows for the evolutionary introduction of depth perception into the existing digital TV framework. The approach is based on the joint transmission of video and associated depth information. Monoscopic or stereoscopic "virtual" views of the scene are generated by means of depth-image-based rendering (DIBR) techniques.

Discussions with major electronic companies reveal that 3D is expected to be the next great revolution in the history of TV. So far almost all approaches are based on the idea of "stereoscopic" video, i.e. the capture, transmission and display of two separate video streams, one for the left eye and one for the right eye. The main drawback of these systems is their inflexibility regarding depth reproduction, different display technologies, and different viewing conditions.

Recent advances in a number of different key technologies, especially computer vision and computer graphics, allow us to overcome these restrictions and to develop a new, more flexible approach based on the joint transmission of video and associated depth information [1]. Monoscopic or stereoscopic views of the scene are then generated by means of depth-image-based rendering (DIBR) techniques. An overview of the necessary video processing chain is shown in the figure.

The 3D video data are generated by either recording new content using a novel depth camera or by converting existing 2D video material to 3D (3D Content in the figure). The video and the associated depth information are then transmitted in a way that is backwards compatible to current 2D digital TV (Coding and Transmission). At the receiver side, one or more virtual views are synthesised using DIBR techniques to reproduce the scene on future auto-stereoscopic single or multi-user displays. Alternatively, head-motion parallax can be provided even on conventional 2D displays to provide the viewer with some initial, limited impression of depth. This allows for the evolutionary introduction of depth perception into the existing 2D digital TV framework.

Another point that should be mentioned is that the new approach also provides scalability in terms of depth perception. This is particularly important because perception studies have indicated that there are differences in depth appreciation across the age groups.



Outline of the video processing chain for a new approach to 3D-TV

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1 Max-Born-Institut, Berlin, DE
2 T-Systems Nova, Berlin, DE
3 Corning Optical Fiber, Slintshire, GB
4 Alcatel, Stuttgart, DE
5 University of Stuttgart, DE
6 Technical University München, DE
7 Technical University Berlin, DE
8 FhG IZM, Teltow, Berlin, DE
9 University of Erlangen Nürnberg, DE
10 Infineon Technologies AG, Erlangen, DE
11 University of Illinois, USA
12 Carl Zeiss Jena, DE
13 MergeOptics, Berlin, DE
14 Lucent Technologies, Nürnberg, DE
15 Denmark Technical University, Kopenhagen, DK
16 GiGA-Intel, DK
17 u^2t Photonics AG, Berlin, DE
18 University of Applied Sciences, Wernigerode, DE
19 Infineon Technologies AG, Regensburg, DE
20 Humboldt-Universität zu Berlin, DE
21 University of California, Santa Cruz, USA
22 Fujitsu Laboratories Ldt., Wakamiya, JP
23 LayTec GmbH, Berlin, DE
24 Jenoptik, Jena, DE
25 Philips Eindhoven, NL
26 Stanford University, USA
27 FH Schmalkalden, DE
28 Technical University Eindhoven, NL
29 Royal University of Leuven, BE
30 3DV Systems, IL
31 De Montfort University, GB
32 UBVideo, CA
33 NTT DoCoMo, DE
34 FHTW Berlin, DE
35 DResearch GmbH, Berlin
36 TU Delft, NL
37 TNO, NL
38 Sony, Basingstoke, GB
39 Heriot-Watt-Univesity, GB
40 BT Exact, GB
41 University of Rostock, DE
42 Technical University Ilmenau, DE
43 SciWorx GmbH, DE
44 Dicas, Berlin, DE
45 Fraunhofer-Verbund Mikroelektronik, Berlin, DE
46 Nokia Research Center, Dallas, TX, USA
47 Immersive Media, Portland, OR, USA
48 Siemens München, DE
49 Motorola, AU
50 SEGA, Tokyo, JP
51 Microsoft, USA

PATENT APPLICATIONS

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ACCEPTANCE OF CHAIRS

H. Boche took up a **professorship in the area of communication systems**, TU Berlin, Fakultät IV (Elektrotechnik und Informatik), Institut für Telekommunikationssysteme, FG Mobilkommunikation.

T. Sikora took up a **professorship in the area of communication systems**, TU Berlin, Fakultät IV (Elektrotechnik und Informatik), Institut für Telekommunikationssysteme, FG Nachrichtenübertragung.

DOCTORATE THESES

G. Heising, **Effiziente Bewegbildcodierung unter Verwendung einer gitterbasierten zeitlichen Prädiktion (Efficient coding of moving pictures using grid-based temporal prediction)**, Prof. P. Noll (TU Berlin, Fakultät IV), Prof. J. Ohm (RWTH Aachen).

D. G. Rabus, **Realization of optical filters using ring resonators with integrated semiconductor optical amplifiers in GaInAsP/InP**, TU Berlin, Fakultät IV (Elektrotechnik und Informatik), Institut für Hochfrequenztechnik, Prof. Petermann, http://edocs.tu-berlin.de/diss/2002/rabus_dominik.htm, Der Andere Verlag ISBN 3-89959-022-8.

M. Schubert, **Power-aware spatial multiplexing with unilateral antenna cooperation**, TU Berlin, Fakultät IV (Elektrotechnik und Informatik), Prof. H. Boche.

K. Seifert, **Evaluation multimodaler Computer-Systeme in frühen Entwicklungsphasen. Ein empirischer Ansatz zur Ableitung von Gestaltungshinweisen für multimodale Computer-Systeme (Evaluation of multimodal computer systems in early phases of development - An empirical approach to derive evidence for the design of multimodal computer systems)**, TU Berlin, Fakultät V (Verkehrs- und Maschinensysteme), Prof. K.-P. Timpe, Prof. L. Blessing.

DIPLOMA THESES

F. Boczianowski, **Monolithisch 40 GHz-modengekoppelte Laser für die OTDM-Nachrichtenübertragung (Monolithically integrated 40 GHz-mode-locked laser for OTDM-communications)**, TU Berlin, Fakultät II (Mathematik und Naturwissenschaften), Optisches Institut. Supervisors at HHI: B. Hüttl, R. Kaiser.

S. Brahma, **Untersuchungen zum Phasenrauschen einer optischen Pulsquelle (Investigations on phase noise of an optical pulse source)**, TU Berlin, Fakultät IV (Elektrotechnik und Informatik), Institut f. Hochfrequenztechnik. Supervisor at HHI: H. G. Weber.

G. Bramann, **Measurements and analysis of**

next-generation optical fibre transmission sections with particular reference to dispersion management, HHI jointly with University of Central England. Supervisor at HHI: E.-J. Bachus.

D. Hildebrand, **Untersuchung von hybriden Verfahren zur Videocodierung (Exploration of hybrid video coding methods),** TFH Berlin, Fachbereich II (Mathematik). Supervisor at HHI: D. Marpe.

A. Jacob, **Optimierung der Faser-Chip-Kopplung am Laserschweißplatz. Schwingungsunterstützte Minimierung der Haftreibung bei der Justage im Sub-Mikrometerbereich (Optimizing the fiber-chip-coupling at the laser welding machine. Vibration backed minimization of the static friction with adjustments in the submicron-area),** FHTW Berlin, Mikrosystemtechnik. Supervisor at HHI: Th. Rosin.

D. Kossack, **Untersuchungen zum Einfluß von Korrelationseigenschaften der Spreizsequenzen in CDMA-basierten Mobilfunksystemen mit Mehrnutzerempfängern (Investigation of the influence of correlation properties of spreading sequences in CDMA-based mobile communications systems with multiuser receivers),** TU Berlin, Fakultät IV (Elektrotechnik und Informatik), Insitut für Telekommunikationssysteme. Supervisor at HHI: S. Stanczak.

H. Louchet, **Control modulation technique for optical performance monitoring in WDM networks with phase modulated client signals,** TU Berlin, Fakultät IV (Elektrotechnik und Informatik), Institut f. Hochfrequenztechnik. Supervisor at HHI: M. Rohde.

M. Malach, **Dynamisches Verhalten der Raman-Verstärkung (Dynamic properties of the Raman amplification in case of WDM transmission),** TU Berlin, Fakultät IV (Elektrotechnik und Informatik), Institut f. Hochfrequenztechnik. Supervisor at HHI: E. Schulze.

K. Mertens, **Untersuchung neuer Übertragungsverfahren in dynamischen Glasfasernetzen mit Wellenlängen-Multiplextechnik (Investigation of novel transmission schemes in dynamical fibre WDM networks),** TFH Berlin, Fachbereich VII (Elektrotechnik und Feinwerktechnik). Supervisors at HHI: M. Rohde, E.-J. Bachus, C. Caspar.

F. Neumann, **Automatische Detektion der Augen in 2D Videosequenzen für multimodale Mensch-Computer-Interaktion (Automatique eye detection in 2D video sequences for multi modal human-computer-interaction),** TU Berlin, Fakultät IV (Elektrotechnik und Informatik) Institut f. Technische Informatik und Mikroelektronik. Supervisor at HHI: J. Liu.

S. Ritter, **Experimentelle Charakterisierung von 1,55 µm-Fabry-Perot-Halbleiterlasern mit integrierten sättigbaren Absorber, für Anwendungen in hochratigen Pulsquellen (Experimental characterisation of 1,55 µm-Fabry-Perot-semiconductor laser with integrated saturable absorber for applications in high bit-rate pulse sources),** TFH Berlin, Fachbereich II (Mathematik-Physik-Chemie) Fachgruppe Physik: Laseranwendungen und Optoelektronik. Supervisors at HHI: B. Hüttl, R. Kaiser.

D. Schröder, J. Roeske, **Bildqualität von analog und digital produzierten Bildfolgen (Image quality resulting from analog vs. digital cameras),** FU Berlin, FB 12 (Erziehungswissenschaften). Supervisor at HHI: J. Faber.

GRADUATE THESES

P. Voigt, **Entwicklung eines steuerbaren Videoservers zur Übertragung von MPEG-4 Echtzeitvideoströmen (Implementation of a controllable server for real-time MPEG-4 video streaming),** TU Berlin, Fakultät IV (Elektrotechnik und Informatik) Institut für Telekommunikationssysteme. Supervisor at HHI: K. Müller.

T. Trietz, **Aufbau eines Meßmikroskops (Building a microscop for measurements),** FHTW Berlin, Mikrosystemtechnik. Supervisor at HHI: Th. Rosin.

S. Wendler, **Untersuchen von Schweißparametern für das Dichtschweißen von OEICs mittels Laserschweißen (Investigation of parameters for hermetic sealing of OEICs by means of laser welding),** FHTW Berlin, Nachrichtentechnik. Supervisor at HHI: Th. Rosin.

L. Molle, **Untersuchung zum Dispersionsmanagement in hochratigen Wellenlän-**

genmultiplex-Glasfasernetzen (Investigation on dispersion management for high bitrate WDM networks), TU Berlin, Fakultät IV (Elektrotechnik und Informatik), Institut für Telekommunikationssysteme. Supervisors at HHI: E.-J. Bachus, R. Freund.

H. Nguyen, **Analyse von Multiple Input Multiple Output Funkkanälen anhand von Messungen (Analysis of MIMO radio channels based on Measurements)**, TU Berlin, Fakultät IV (Elektrotechnik und Informatik) Institut für Telekommunikationssysteme. Supervisor at HHI: V. Pohl.

ORAL PRESENTATIONS

K.-D. Langer, **KomNet – On the way to the broadband Internet**, DFN-Workshop "Optische Netze", Berlin, 8./9.1.2002.

H. Boche, M. Schubert, **Joint writing-on-dirty-paper precoding and downlink beamforming achieve the ultimate capacity**, Universität Bremen, 5.2.2002.

V. Jungnickel, V. Pohl, T. Haustein und C. v. Helmolt, **Erste Ergebnisse zu breitbandigen MIMO Kanalmessungen bei 5.2 GHz**, Space-Time Signalprocessing Workshop, Institut für Telekommunikation und Hochfrequenztechnik (ITH), Universität Bremen, 5.2.2002.

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H. Boche, M. Schubert, **Space-Time-Signalprocessing für die Mobilkommunikation** (invited), Universität Bremen, 6.2.2002.

K. Schenke, **Mixed Reality, Interaktion mit virtuellen Objekten**, CeBIT 2002 Future Talk, Hannover, 16.3.2002.

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K. Schenke, **Autostereoskopische Displays, Grundlagen, Realisierungskonzepte, Anwendungen**, Best Practice-Seminarreihe Prof. Krömker, Fraunhofer AGC (Anwendungszentrum Computergraphik in Chemie und Pharmazie), Frankfurt, 16.5.2002.

T. Wiegand, **H.26L Video Transmisson in 3G Wireless Environments**, Intern. Conf. on Third Generation Wireless and Beyond, San Francisco (CA, USA), May 2002.

V. Jungnickel, **Zum Einfluß verschiedener Antennengeometrien auf die MIMO-Kapazität (indoor/outdoor)**, Space-Time Signalprocessing Workshop, Ilmenau, 13.-14.6.2002.

V. Pohl, **Die Struktur von linearen Entzerrfiltern für frequenzselektive MIMO Kanäle**, Space-Time Signalprocessing Workshop, Ilmenau, 13.-14.6.2002.

K. Müller, **Semantische Inhaltsbeschreibung durch MPEG-7**, Internationales Symposium Vernetzte Fernsehproduktion Köln, June 2002.

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R. Schäfer, **Video based Services for DAB/DVB-T and UMTS Using Novel Compression Methods**, Workshop of the RegTP, Mainz (DE), 10.7.2002.

K. Biermann, D. Nickel, K. Reimann, M. Woerner, T. Elsaesser, H. Künzel, **Ultrafast nonlinear optical response at wavelengths around 1.55 mm of in low-temperature-grown GaInAs/AlInAs quantum wells** (poster), 26th Intern. Conf. on the Physics of Semiconductor, Edinburgh (GB), 29.7.-2.8.2002.

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E. Jorswieck and H. Boche, **Sum Capacity Optimization of the MIMO Gaussian MAC** (invited), Universität Bremen, 10.-11.9.2002.

A. Sezgin, **Joint decoding and channel estimation for low-complexity STC** (invited), Universität Bremen, 10.-11.9.2002.

A. Smolic, **The Emerging H.264/AVC Video Coding Standard**, Workshop on Upcoming Video Coding Standards, Vrije Universiteit Brussel (VUB), Brussels (BE), 30.9.2002.

T. Wiegand, **Context-Based Adaptive Binary Arithmetic Coding in JVT/H.26L**, International Conference on Image Processing, Rochester (NY, USA), Sept. 2002.

T. Wiegand, **Performance Comparison of Video Coding Standards using Lagrangian Coder Control**, International Conference on Image Processing, Rochester (NY, USA), Sept. 2002.

T. Wiegand, **The Emerging H.264/AVC Video Coding Standard**, IBM, Yorktown (NY, USA), Sept. 2002.

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M. Rohde, **Prüfmodulationsverfahren zum "Performance Monitoring" in 10 Gb/s WDM-Systemen**, DFG-Kolloquium, München, 7./8.10.2002.

E. Schulze, **Dynamisches Verhalten in WDM-Systemen: Vergleich von verteilter Raman-Verstär-kung und EDFA-Ketten**, DFG-Kolloquium, München, 7./8.10.2002.

M. Seimetz, **Vorteile und Realisierbarkeit des optischen Homodynempfangs in zukünftigen WDM-Netzen**, DFG-Kolloquium, München, 7./8.10.2002.

B. Hüttl, **Experimental characterization of monolithic 40GHz mode-locked lasers on GaInAsP/InP**, Seminarvortrag im Rahmen des Forschungsseminars "Mathematische Modelle der Photonik, Minisymposium über Mode Locked Laser", Veranstalter: WIAS, HU-Berlin, 24.10.2002.

A. Nesterov, U. Troppenz, **Laser, Filter und Wellenlängenkonverter auf der Basis aktiver GaInAsP Mikroringresonatoren; Ziel, Modelle, Zwischenergebnisse**, Seminarvortrag im Rahmen des Forschungsseminars "Mathematische Modelle der Photonik", Veranstalter: WIAS, HU-Berlin, 31.10.2002.

H. H. Yao, **Polymer waveguide devices for DWDM applications** (invited), Kwangju Institute of Science and Technology, Kwangju (KOR), 1.11.2002.

H. H. Yao, **Polymer waveguide devices for DWDM applications** (invited), Electronic Telecommunications Research Institute (ETRI) and ZenPhotonics, Daejon (KOR), 2.11.2002.

R. Schäfer, **Fundamentals of DVB and DVB-T**, Seminar on Digital TV of Freie Universität and Humboldt-Universität, Humboldt University Berlin, 4.11.2002.

M. Seimetz, **Vorteile und Realisierbarkeit des optischen Homodynempfangs in zukünftigen WDM-Netzen**, TU Berlin, Seminar zur optischen Nachrichtentechnik, 22.11.2002.

E. Schulze, **Dynamics of Raman Amplified WDM Links**, Workshop on optical WDM-transmission and networks, jointly with COM, HHI, T-Systems, TZ Berlin, 25.11.2002.

M. Seimetz, **Homodyne Detection in Future WDM-Networks, Promises & Problems**, Workshop on optical WDM-transmission and networks, jointly with COM, HHI, T-Systems, TZ Berlin, 25.11.2002.

E. Jorswieck and A. Sezgin, **An iterative Signal Processing Algorithm (ISIP) for MIMO systems**, Space-Time-Signalprocessing Workshop, Universität Ulm, Nov. 2002.

S. Golka, **Design und Herstellung photonischer Kristalle in InP**, Seminarvortrag im Rahmen der Veranstaltung "Photonische Kristalle – Modellierung, Simulation und Technologie", Konrad-Zuse-Zentrum (ZIB), Berlin, 2.12.2002.

S. Gouraud, D. Franke, P. Harde, A. Paraskevopoulos, **Iron doping behaviour**

in InP grown by LP-MOVPE in the presence of Tertiarybutylchloride, DGKK Workshop, Magdeburg (DE), 12.12.2002.

K. Biermann, J. Böttcher, H. Künzel, **MBE Wachstum von GaInAs/AlAsSb MQWs auf InP für "kurzwellige" Intersubband-Übergänge**, DGKK Workshop, Magdeburg (D), 13.12.2002.

J. Faber, **Probleme und nicht verbale Verfahren zur Erfassung von Stimmungen, Gefühlen und Bedürfnissen**, VμE-Arbeitskreis Perceptual User Interface, Erlangen, 18.12.2002.

C. Fehn, P. Kauff, M. Op de Beeck (Philips, NL), F. Ernst (Philips, NL), W. Ijsselsteijn (TU/e, NL), M. Pollefeys (KU Leuven, BE), L. Van Gool (KU Leuven, BE), E. Ofek (3DV Systems, IL), I. Sexton (De Montfort University, GB), **IST Project ATTEST – An Evolutionary and Optimised Approach on 3D-TV**, Invited Talk at Picture Coding Symposion Japan (PCSJ 2002), Shizuoka (JP), Dec. 2002.

LECTURES

H.-G. Bach, Grundlagen der optoelektronischen Halbleiterbauelemente, TU Berlin

H.-G. Bach, Messverfahren für Halbleiterbauelemente, TU Berlin

E.-J. Bachus, Photonische Kommunikationsnetze, TU Berlin

H. Boche, Digitale Mobilkommunikation I, 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

P. Eisert, Visualisierung, Codierung und Übertragung virtueller 3D Welten, TU Berlin

G. Heising, Digitale Videotechnik, TFH Berlin

L. Ihlenburg, Entwicklungstendenzen der Multimediakommunikation, TU Berlin

V. Jungnickel, Übertragungsverfahren, TU Berlin

V. Jungnickel, Adaptive Übertragungssysteme, TU Berlin

I. Keller, Klassifikation in der Nachrichtentechnik, TU Berlin

A. Kortke, Praktikum Digitale Mobilkommunikation I, 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 Nachrichtentechnik, TFH Berlin

O. Schreer, Stereobildverarbeitung in der Videokommunikation, TU Berlin

P. Stammnitz, Einführung in Kanalcodierungsverfahren, TU Berlin

H. G. Weber, Grundlagen und Anwendungen der linearen und nichtlinearen Faseroptik, TU Berlin

T. Wiegand, Digitale Bildkommunikation, TU Berlin

WORKSHOPS ORGANISED

Nokia Leading Science 4 Program, HHI Berlin, January

Final review of national R&D Programme KomNet, HHI Berlin, April

ITG-FKTG Workshop Media Streaming, HHI Berlin, June

IST Programme: BUSMAN, 2nd Managing Committee Meeting, HHI Berlin, July

2. open TransiNet Workshop, TransiNet:

Innovative Transportnetze für das Breitband Internet, HHI Berlin, October.

ITG-Workshop, Breitbandige Zugangsnetze und Integrierte Inhausnetze, HHI Berlin, October.

Mensch-Maschine-Schnittstellen: Ambient Intelligence, Workshop organized jointly with FhG µE-Verbund, HHI Berlin, October

CONTRIBUTIONS TO EXHIBITIONS

CeBIT 2002, Hanover, March:
Mixed Reality interaction with virtual objects
Digital cinema / Digital projection systems

FKTG 2002, Zurich (CH), June:
Interactive streaming of high-resolution panoramic views
H26L streaming
Multi projection system

Internationale Frachttage der Lufthansa Cargo AG, Lufthansa Bildungszentrum Seeheim, June:
Mixed Reality interaction with virtual objects

ITG/FKTG – Workshop Media – Streaming, Berlin, June:
ISMA-compatible and platform independent streaming solutions
MPEG-4 Encoder-ASIC for mobile streaming-applications
BMS-Project
Interactive streaming of high resolution panoramic views
OMSA-Project
H.26L Codec

IBC 2002, Amsterdam (NL), September:
Immersive projection system (Multi-projection)
H26L streaming
HiCon^{32} video converter
MPEG-4 video codec ASIC for mobile applications
Interactive streaming of high resolution panoramic views

COMMITTEE ACTIVITIES

Standardisation Committees

DIN

DVB Technical Module: Member

IPC, Committee 5-20, Subcommittee 5-25: Member

ISO/MPEG

ITU-T, SG 16, Associated Rapporteur

JVT, Co-chair

Research Program Committees

COST 266, Progress of Photonic Infrastructure towards the IT-Age: Member MCM

COST 267, Semiconductor devices for signal processing WG2: Chairman

COST 268, Management Committee: Member (deputy)

IST (Inform. Society Technologies): Evaluator

Strategische Plattform Informationstechnik: Member

Conference and Workshop Program Committees

CLEO Technical Program Committee: Member

10th Dortmunder Fernsehseminar: Program Committee

ECOC Technical Program Committee: Member

11th European Conference on Integrated Optics (ECIO '03), 2003, Prague (CZ): Program Committee Member

European Leica Beamwriter Users Meeting: Chairman

Human Factors in Telecommunications: Permanent Steering Committee

IC MOVPE-XI, Berlin 2002: Program Committee Member

14th Intern. Conf. 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

Net & Home – Congress, Technical Program Committee: Member

Packet Video Workshop: Program Committee

Potsdamer Film Kolleg: Program Committee

SPIE Conf. on Design an Fabrication of Planar Optical Waveguide Devices and Materials, San Diego (USA): Program Committee Member

Technisch-Wissenschaftliches Forum IFA '03

VIProm Com '02: Program Committee

VTC Spring 2003 TPC: Member

Editorial Boards

IEEE ICME Track Chair

Institute of Physics (GB)/Semiconductor Science and Technology: Referee

Springer Verlag Berlin, Heidelberg, Series "Photonics": Co-Editor

Other Committees

Aspen Institut Berlin: Member

Competence Center for the Application of Nanostructures in Optoelectronics (NanOp): Member of Executive Board

FKTG, Urtel-Preis-Komitee: Curatorship

11th International Conference on Metal-Organic Vapour Phase Epitaxy (IC MOVPE XI), Berlin: Public Relations

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 GmbH, Berlin: Advisory Committee

Münchner Kreis, Supranational Association for Communications Research: Research Committee

OPTEC BB, Berlin: Member

TSB-Technologiestiftung Innovationszentrum Berlin: Board of Curators

VDI optische Technologien: Advisory Board

EXCHANGE PROGRAM

Scientists Visiting HHI

K. Biermann, Max-Born Institut, Berlin, financed by MBI, for three months

R. Böhnke, Universität Bremen, financed by Universität Bremen, for two months

B. Cai, Tohoku University, Sendai (J), financed by Tohoku University, for three months

S. Dressler, Humboldt Universität zu Berlin, financed by HUB, for one year

R. Freund, Fa. VPI, Berlin, financed by VPI, for ten months

F. Futami, Fujitsu Laboratories Ltd., Nakahara-ku, Kawasaki (J), financed by Fujitsu, for six weeks

S. Gouraud, Alcatel CIT/OPTO+, Marcoussis (F), financed by Alcatel Paris, for one year

V. Haisler, Institute of Semiconductors, Novosibirsk (RUS), financed by Institute of Semiconductors, for nine months

Y. Horita, Toyama University, Toyama (J), financed by Toyama University, for three months

T. Ido, Hitachi Ltd., Central Research Laboratory, Tokyo (J), financed by Hitachi Ltd., for seven months

I. Koichi, Kanazawa University (J), financed by the Japanese Government, for one month

A. Kortke, TU Berlin, financed by TUB, for eight months

V. Kravcenko, TU Berlin, financed by TU Berlin, for one year

M. Lämmlin, TU Berlin, financed by TUB, for five months

N. T. Quang Le, Technical University of Denmark, Lyngby (DK), financed by TU of Denmark, for three months

Ei Ei Minn, Ministry of Sience and Technology, Yagon (MM), financed by DAAD, for six months

M. Mrak, University of Zagreb (HR), financed by DAAD, for six months

T. Oechtering, TU Berlin, financed by TUB, for three months

N. Sabelfeld, MergeOptics GmbH, Berlin, financed by MergeOptics GmbH, for two months

L. Schares, ETH-Zürich, Zürich, (CH), financed by ETH-Zürich, for two weeks

T. Strohmer, University of California, Stanford University, Davis, (CA, USA), financed by HHI, for two weeks

S. Watanabe, Fujitsu Laboratories Ltd., Nakahara-ku, Kawasaki (J), financed by Fujitsu, for five weeks

HHI Scientists Visiting Foreign Institutes

A. Festag, TU Berlin, financed by HHI, for one year

A. Sezgin, University Bremen, financed by HHI, for two months, and Arizona State University (USA), financed by HHI, for three weeks

COOPERATIONS

Industry

Acterna, Eningen

A.C.T. Kern, Donaueschingen

Actryon GmbH, Berlin

adaptif Photonics GmbH, Hamburg-Harburg

Aifotec GmbH, München

Alcatel SEL, Stuttgart

Alcatel, Paris

Alpha Baumanagement, Aachen

ATIP GmbH, Frankfurt/M.

ASL – Applied Science Laboratories, Bedford, (MA, USA)

AVRIO Technologies Europe GmbH, Berlin

AXON Photonics, Livermore (CA, USA)

Bayerischer Rundfunk, München

BBC, London

Bertelsmann, Gütersloh

Blaupunkt-Werke GmbH, Hildesheim

British Telecom, Martelsham Heath, Corning (GB)

Btexact Technologies, London (GB)

Canto, Berlin

Carl Zeiss, Jena, Oberkochen

com center, Kopenhagen

CRL Opto Ltd., Hayes (GB)

DaimlerChrysler, Ulm

das werk, München

Dr. Detlef Rose Fotomasken Mikroelektronik, Bergisch Gladbach

D-Research Digital Media Systems GmbH, Berlin

EPIGAP Optoelektronik GmbH, Berlin

Ericsson Eurolab, Aachen

Fiber Core, Jena

framepool München

Fresnel Optics GmbH, Apolda

Fujitsu Laboratories Ltd., Wakamiya (JP), London

GWS Photonics Israel Ltd., Ramat Gan (IL)

Hitachi Central Research Laboratory, Tokyo, Cambridge (GB)

HoloEye GmbH, Berlin

Infineon Technologies, Berlin, Regensburg, München

ISIS Optronics, Mannheim

IVU Traffic Technologies, Berlin

JDS Uniphase, Eindhoven (NL)

Kerpenwerke, Stolberg

Laser Components GmbH, Olching

Laytec GmbH, Berlin

Leybold Optics Dresden GmbH, Dresden

Loewe-Opta GmbH, Kronach

Lucent Technologies, Nürnberg, Holmdel (NJ, USA)

Lumics GmbH, Berlin

MAZ level one GmbH, Hamburg-Harburg

Medav Digitale Signalverarbeitung GmbH, Uttenreuth

Medienanstalt Sachsen-Anhalt

MergeOptics GmbH, Berlin

Mikrom, Berlin

moove, Leverkusen

Motorola U.K. Research Lab, Basingstoke (GB)

NTT – Nippon Telegraph and Telephone Corporation, Tokyo

Nokia, Espoo (SF)

Optibase, Herzliya (IL)

Opto+, Paris

OptoSpeed SA, Darmstadt, Zürich

Philips BV, Eindhoven (NL)

Quantum Devices Inc. (QDI), Yorba Linda, (CA, USA), Berlin

Robert Bosch GmbH, Hildesheim, Stuttgart

sci-worx, Hannover

Sentech Instruments GmbH, Berlin

Siemens AG, Berlin, München, Regensburg

Tecsi, Paris

Telefónica, Madrid

Telenor, Oslo

Teracom AB, Stockholm

Tesat-Spacecom GmbH & Co. KG, Backnang

Thales Research & Technology France, Orsay (FR)

TNO Physics and Electronics Laboratory, Den Haag (NL)

TOPTICA Photonics AG, München

T-Systems Nova, Berlin, Darmstadt

u^2t Photonics AG, Berlin

Vcon Telecommunications Ltd. (IL)

Virtual Photonics Inc., Berlin, Melbourne, Freehold (USA)

Vodafone Ltd., Newbury (GB)

Xignal Technologies AG, München

2SK Media Technologies, Berlin

Universities and Institutes

Brunel University, Uxbridge (GB)

Denmark Technical University, Kopenhagen

DFN-Verein, Berlin

ENST Paris

ETH Zürich

European Broadcasting Union, Genf

Fachhochschule für Wirtschaft und Technik (FHTW) Berlin

Ferdinand-Braun-Institut, Berlin

FhG Einrichtung für Systeme der Kommunikationstechnik, München

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 Institut für Angewandte Informationstechnik, St. Augustin

FhG Institut Siliziumtechnologie, Itzehoe

Freie Universität Berlin, Fachbereich Physik

Heriot-Watt University, Edinburgh (GB)

Hochschule Harz, Wernigerode

Humboldt-Universität zu Berlin

IAF Freiburg

INRIA, Paris

Institut d'Optique, Paris

Institut für Rundfunktechnik, München

Ioffe-Institut, St. Petersburg

IRISA, Rennes (FR)

Konrad-Zuse-Institut, Berlin

Max-Born-Institut, Berlin

MPI Halle

Optotransmitter-Umweltschutz-Technologie e.V., Berlin

Paul-Drude-Institut, Berlin

Queen Mary Westminster College, London

Stanford University (CA, USA)

Technische Fachhochschule Berlin

Tokyo University

TU Berlin

TU Braunschweig

TU Darmstadt

TU Delft (NL)

TU Denmark, Lyngby

TU Hamburg-Harburg

TU Ilmenau

TU München

Universidad Politecnica Valencia (E)

Universität Aachen

Universität Bremen

Universität Dortmund

Universität Duisburg

Universität Karlsruhe

Universität Rostock

Universität Stuttgart

University of Torino (IT)

Universität Würzburg

University of Essex (GB)

University of Gent, IMEC (BE)

University of Illinois at Chicago (USA)

University of North Carolina, Chappel Hill (USA)

Weierstraß-Institut für Angewandte Analysis und Stochastik (WIAS), Berlin

Zentral- und Landesbibliothek, Berlin

Technology Collaboration Networks

NanOp, Berlin

Optec BB, Berlin

Telscom (CH)

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. U2t 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 spinoff, 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 integrated 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.

FRAUNHOFER-HHI AT A GLANCE

Public Research Institute
(Shareholder: Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., Munich)
Total staff at end of 2002: 274 employees

Areas of Research and Development

Photonic Networks

- Design, development and demonstration of optical communication networks and subsystems (access, metro, and customer 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
- Teletraffic engineering for mobile communication systems
- Development of signal processing algorithms for OFDM/Multicarrier systems
- Development of sequences for CDMA applications and multiuser receiver
- Development of optical indoor transmission networks for broadband WLAN
- Analysation of cooperative systems
- MIMO channel measurements and evaluation
- Implementation of MIMO systems
- Development of signal processing algorithms for MIMO systems
- Cooperative receiver and transmitter

Electronic Imaging Technology for Multimedia

- 3D image and video processing
- Image and video coding
- Image and video analysis and synthesis
- Multimedia transmission (IP, mobile, DVB)
- Hardware, software design and implementation of multimedia systems (video, audio, graphics), ASIC and IP design
- Immersive reproduction technologies
- Multi-view capturing and reproduction systems
- Innovative 3D and mixed-reality displays
- Perceptual user interfaces for mobile and desktop applications
- Human-machine interaction
- MPEG-7 based image and video retrieval systems
- Mobile services for citizens
- Sensing people technologies
- Usability engineering

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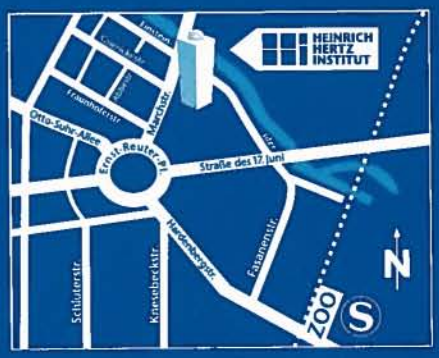
Prof. Dr. Joachim Hesse



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