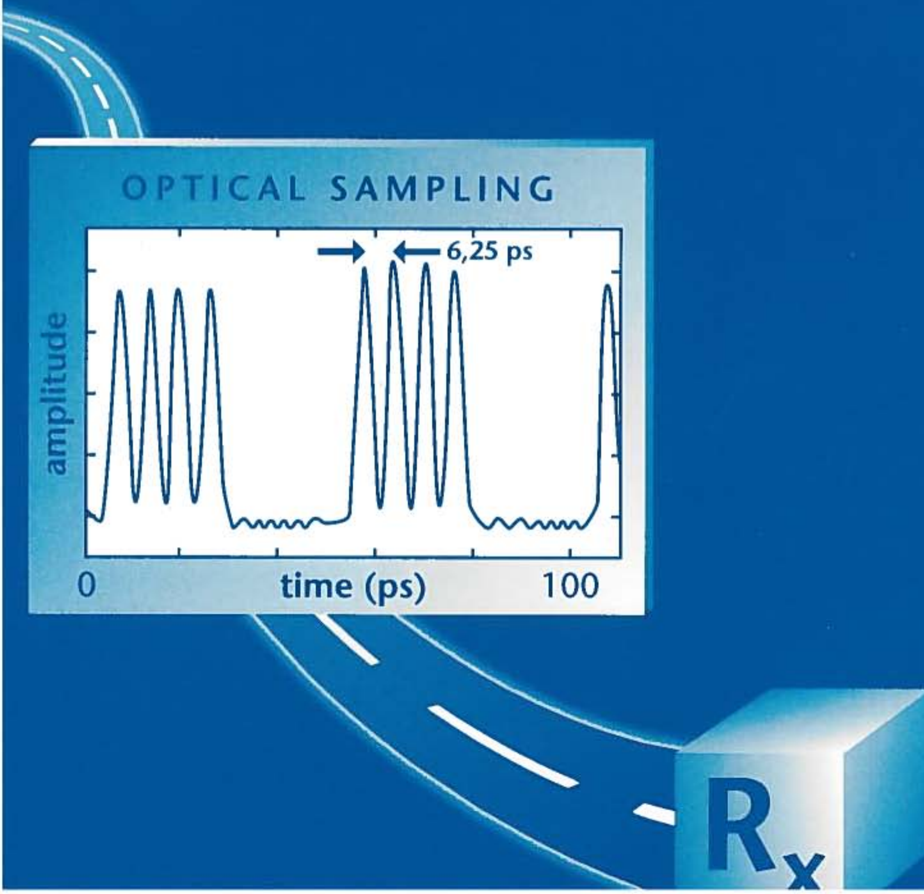
NRICH-HERTZ-INSTITUT

160 Gbit/s



HEINRICH-HERTZ-INSTITUT

REPORT 1999

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Cover illustration:
An optical switch was developed enabling optical sampling of 160 Gbit/s data signals. For the development of this switch a group at HHI received the Philip Morris Research Award 1999.

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FOREWORD

The dawn of the 21st century is cause enough to survey the activities of the Institute during the last ten years – a decade which brought more changes to communication technology than the previous 100 years.

One of the most important innovations of the 20th century is certainly the Internet. It made a reality of the vision that any information should be available to anyone at any place and at any time. From 1994, the true date of birth of the Internet, when the worldwide web spread around the globe, the number of Internet users has grown to 200 million worldwide. For comparison, there are now about one billion telephone users, and it took more than 100 years to reach this number. Only the Internet can bring about the transition from an industrial society to an information society. Information technology, with its Internet boom, has overtaken the automobile industry to become, just before the dawn of the 21st century, the area with the largest turnover and strongest growth.

The development of the communications infrastructure has been profoundly changed by the Internet. The global circuit-switched telephone network, which was established over the last 100 years and which is oriented towards voice services, is now being replaced by a packet-switched network for the Internet. The Internet traffic volume presently grows at a rate of several hundred per cent per year.

The past ten years have been shaped not only by the Internet but also by the evolution of mobile communications. Digital technology, microelectronics and uniform standards were prerequisites for the enormous success of the mobile phone. By the year 2000 there will be 500 million mobile phone users worldwide. In the meantime we have become used to the advantages of mobility. Just as we can phone today from any place, so will access to the Internet from any place be taken for granted in the future. At present the narrowband circuit-switched voice mobile network is developing into a packet-switched data mobile network, the bandwidth of which is increasing step by step. This paves the way for mobile broadband Internet access.

The past decade was also the decade of deregulation of the telecommunications markets. Only deregulation leads to competition, and only competition can result in fee structures that encourage widespread use of the Internet. The importance of competition for the development of the Internet, and thus for the evolution of the information society, cannot be overrated.

Work at the HHI is directed entirely towards the Internet. The HHI has many years of experience in the areas of photonic networks, photonic components and photonic integrated circuits as well as electronic imaging technology. Photonics is the crucial key technology for the Internet infrastructure. Work on electronic imaging technology deals with image signal processing – in the future broadband Internet, most services will be image services – and with the development of interactive and user-friendly terminals and applications.

When, in the mid nineties, voice mobile networks (GSM) began to develop into broadband data mobile networks (IMT 2000/UMTS) as a mobile access to the Internet, it became obvious that research in the area of mobile communications would face an enormous challenge. This was the right moment for HHI to include broadband mobile communications in its research programme, another key technology for the future Internet infrastructure. The department Broadband Mobile Communications deals with a number of topics in the area of space-time signal processing. The goal is to develop new ways, using modern mathematical methods, of making better use of the valuable bandwidth resources.

HHI research in the area of photonic networks has so far focussed on the physical layer of the OSI layer model. The higher protocol layers are presently undergoing major changes. For example, enormous progress in photonics has given the physical layer functionalities that were previously reserved for the upper protocol layers. Also, the Internet protocol (IP) questions the classical SDH/ATM paradigme (e.g., by IP over WDM), and the fixed and mobile networks are now being integrated. This is the right moment for the HHI, in cooperation with several university institutes, to start work on the higher protocol layers in order to participate from the beginning in the approaching revisions of the traditional protocol stacks.

In its three research areas the institute has, during the past decade, achieved the following outstanding results:

Photonic Networks and Components

- Realisation of WDM networks with extremely small channel spacings (less than 10 GHz)
- Construction of a WDM ring test bed for fundamental research into transparent optical networks and for the development of network simulation tools
- Development into the German centre of excellence for high rate optical time-division multiplexing technology
  - All-optical 3R regeneration for 40 Gb/s (in cooperation with Alcatel France)
  - Optical sampling at 160 Gb/s with a time resolution less than 1 ps
  - Optical signal processing at 640 Gb/s with semiconductor components
- Development into the German centre of excellence for monolithically integrated optoelectronic circuits on InP
  - Monolithically integrated heterodyne receiver – the highest integration density ever obtained in an optoelectronic circuit
  - Monolithically integrated optoelectronic receiver for 40 Gb/s
  - Waveguide-integrated photodiode with 70 GHz bandwidth

Electronic Imaging Technology

- Development of an interactive autostereoscopic display with gaze control
- Development of a 40 inch autostereoscopic multi-user display
- Development of "virtual-reality offices" for telework applications
- Evaluation of interactive media through usability engineering
- Chair of the MPEG video group
- Development into the German centre of excellence for MPEG-2 and MPEG-4
  - Realisation of a single-chip MPEG-2 decoder for HDTV
  - Realisation of an MPEG-4 decoder
  - Realisation of a virtual video conference system based on MPEG-4

Broadband Mobile Communications

- Generation of microwave signals with sub-Hertz linewidth for base stations of cellular broadband radio networks using optical sideband injection locking technology. Bidirectional transmission experiments with 155 Mb/s at 60 GHz.
- Development of a new closed-form beamforming algorithm for smart antennas that gives the maximum possible directivity for a given number of zeros. This makes it possible to control the directivity in real time in future SDMA systems. Use of the new algorithm in 2D rake receivers.
- Development of new mobility models for the planning and evaluation of mobile radio systems. Development of new methods for modelling handover traffic with various statistics.
- Development of new spreading sequences with very good autocorrelation and cross-correlation properties for CDMA-based mobile radio systems

The HHI has been honoured for its work several times in the past ten years:

1991 Awarded the Eduard-Rhein Technology Prize for work in the area of optical wavelength division multiplex technology.

1999 Awarded the Philip Morris Research Prize for work in the area of high rate optical time division multiplex technology

1999 Nominated for the German Future Prize (Prize for Technology and Innovation of the Federal President), and accepted into the circle of the four best candidates for work in the area of high rate optical time division multiplex technology

1999 Nomination for the multimedia prize DigiGlobe (Category Research and Technology), and accepted into the circle of the three best candidates for work in the area of autostereoscopic displays

1999 Chosen for Expo 2000 as exhibits for Berlin:
- The Internet of the future – photonic ICs
- Gaze-controlled 3D multimedia workstation

The Heinrich-Hertz-Institut has been evaluated four times in recent years:

- Zentralverband der Elektrotechnik und Elektronikindustrie (ZVEI) e.V., October 1993 *(German electrical and electronic manufacturers' association)*
- Wissenschaftsrat *(Science Council)*, June 1994
- Zentralverband der Elektrotechnik und Elektronikindustrie (ZVEI) e.V., April 1997 *(German electrical and electronic manufacturers' association)*
- Wissenschaftsrat *(Science Council)*, April 1998

Each time the evaluation was "good" to "very good". The last evaluation in April 1998 by the Science Council was: "The research achievements of the HHI are very good and internationally recognised".

The evaluations in 1993 and 1994 by the Zentralverband der Elektrotechnik und Elektronikindustrie and by the Wissenschaftsrat, respectively, were of particular importance for the further development of the Institute. Both evaluations confirmed the high scientific standing of the Institute, but they suggested that the Insitute should look for closer ties with industry. The HHI took this very seriously, and with the full agreement and support of the HHI Supervisory Board and Scientific Advisory Committee, began immediately to increase its collaboration with industry. The Board also instituted a new patent policy in July 1994 and initiated a new drive for patents, including an annual patent prize offered by the chairman of the Supervisory Board, Professor Hesse. Marketing activities to obtain and professionally manage industrial contracts were extended in July 1997. Considerable efforts were also made to introduce modern project and quality management methods.

Starting with the questions asked in the different evaluations, the HHI and its Scientific Advisory Committee have developed a set of criteria which are now used each year to evaluate all projects in the HHI. The results are a valuable instrument that enable the Supervisory Board and the directors to avoid faulty developments. For the project managers these internal evaluations are also good training for future external evaluations.

During 1998/99 a method was developed to measure the performance of the individual departments. The performance score allows departments to compare themselves with others and to identify their weaknesses. It is becoming an important instrument for allocating the Institute's resources in a success-oriented manner.

Nine companies have emerged from the HHI in recent years. Start up companies such as these are also important for improving the Institute's closeness to the marketplace. The HHI supports every initiative by staff who want to market the results of their research.

In 1998 the Scientific Managing Director was awarded the Officers Cross of the order of merit of the Federal Republic of Germany. This was in honour of the contribution of the HHI towards strengthening the competitiveness of the German telecommunications industry.

The recent stronger orientation towards industry in no way compromises HHI's mission to carry out future-oriented research. Having closer ties with industry makes it possible to direct our research planning in line with the strategic goals of industry, and also facilitates the transfer of the research results to industry. Research at the HHI thus embraces the whole gamut: fundamental research, pre-development research and contract research. At present 20%, 60% and 20% of the staff work in these three research categories, respectively. Projects directed by the Deutsche Forschungsgemeinschaft *(German research association)* are important for strengthening the fundamental research.

During the past years several longer-term strategic alliances with industry were formed in the main research areas of photonics, electronic imaging technology and broadband mobile communications.

A further advantage of a stronger orientation towards industry is the finance that comes with the commissions from industry. During the past years the HHI suffered drastic reductions in institutional financing as well as in project grants due to changed funding conditions of Federal Government. In addition, income from research contracts with Deutsche Telekom was also greatly reduced because of changes in their research policy following the privatisation of the former German Federal Post. The Institute managed to compensate for these losses with industry contracts, so that all research activities at the HHI could be continued.

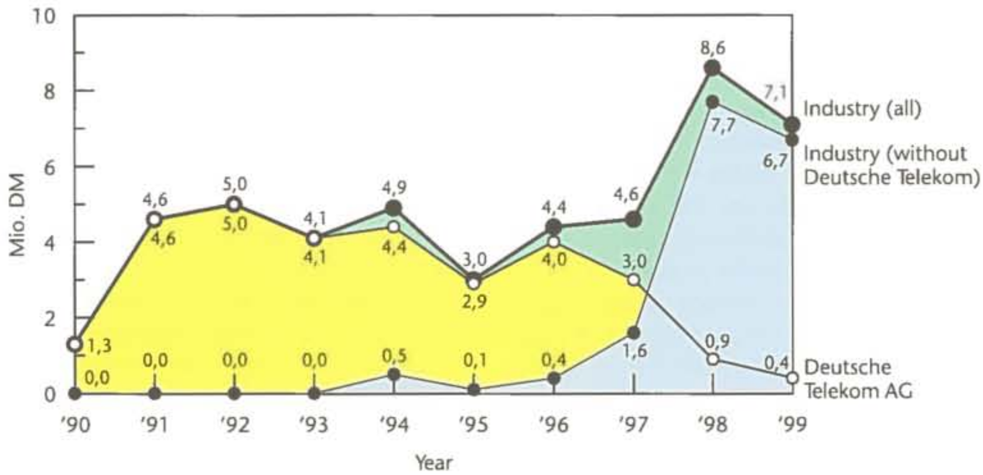
The HHI is greatly involved in teaching at the Technical University of Berlin. In 1999, 18 courses were given by HHI scientists. During the last decade 5 HHI scientists had accepted faculty chairs, and 3 postdoctoral theses and 32 doctoral theses were written at the HHI. During the same period 130 students did their diploma theses.

During the 50th meeting of the Supervisory Board of HHI-GmbH on 13.12.1999, the chair of the Board, Professor Dr Joachim Hesse, was festively farewelled after 12 years in office. The directors thanked Professor Hesse on behalf of the staff for his extraordinary commitment to the Institute. His many years of industrial experience as Director of Research and Technology at Carl Zeiss Oberkochen were an invaluable asset for the HHI during its progress to closer ties with industry. As from 1 January, 2000, Professor Dr Gerd Litfin, chairman of the Management Board of LINOS AG, will be chairman of the Supervisory Board of the HHI, thereby continuing the good tradition of appointing a renowned person from industry to this position.

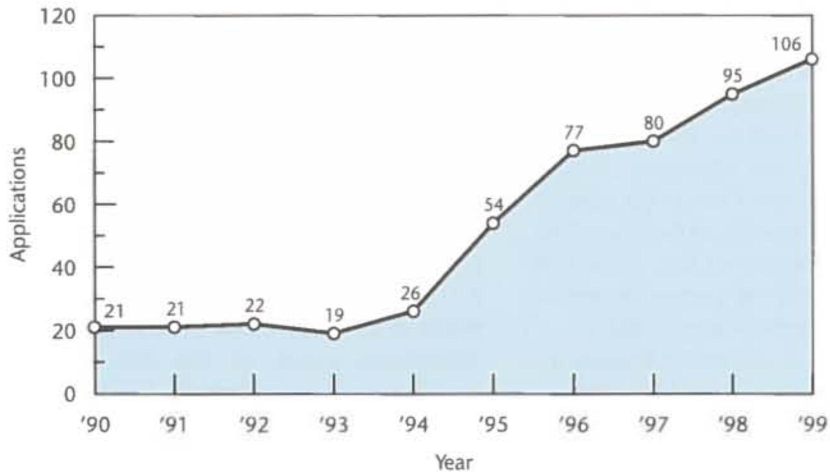
It is our sad duty to report that Gerhard Kohn, Professor Emeritus of Electrical Communications at the University of Stuttgart, who was chairman of the Scientific Advisory Committee from 1993 to 1998, died very suddenly in August 1999. The Institute had a long and intensive cooperation with Professor Kohn as an expert who evaluated and influenced the research and development in the Institute. Credit is due to him in particular for helping the Institute in its efforts to improve its relevance to industry. He was especially interested in obtaining the right balance between fundamental and application-oriented research, and in aligning fundamental and early stage basic research with industry strategies. An unselfish councillor full of ideas has left us. The HHI remembers with gratitude a great and unforgettable person.

The HHI would like to take this opportunity to thank its shareholders, the Supervisory Board, the Scientific Advisory Committee, and the Association of the Friends of the HHI for their willingness to bear with the new orientation of the Institute over the past decade. All efforts would have been doomed had the staff not recognised the need for this change of course. We sincerely thank all the staff for their endeavour and engagement for the future of the Institute. We can be optimistic that together we have correctly paved the way for the Institute to step into the beginning of the Internet age.

Berlin, January 2000
Clemens Baack, Wolfgang Grunow



R&D contracts from Industry (financial volume) 1990 – 1999



Patent applications (inland) 1990 – 1999

Profile of the Institute

Mission, Activities, Personnel and Financing

Information technology is of overriding importance for the development and strength of modern industrial societies, and is itself a sector with high growth rates. Unlike almost any other technology, it is changing our ways of life and work through novel and global communication services that go far beyond conventional telephony. The motor of this development is the Internet, which is expanding at an impressive speed.

The aim of the research and development activities at the Heinrich-Hertz-Institut (HHI) is to expand the principles of information technology and to develop new applications in partnership with industry.

We are now experiencing an explosive rate of increase in the use of the Internet and of mobile communication systems, not only by commercial users but increasingly also by private users. As a result we can assume that by the year 2010 the traffic in data and image services will be ten times greater than the telephone traffic, which will remain approximately steady. If this is to occur, the capacity of the present telecommunication infrastructure must be enlarged significantly, and existing networks must also be modernised using more efficient technologies.

Optical communication technology must be considered for the installed network because of the enormous transmission capacities of glass fibres. The challenge is to continually improve the optical technology and to exploit the transmission capacity of glass fibres to the limit by using wavelength division multiplex and time division multiplex techniques. Due to rapidly growing bandwidth demands, research and development in this field is confronted with short transfer times towards products. Rapid innovation in both systems and components is needed by the IT industry. The HHI responds to this challenge through a manitold of novel projects in the area of **Photonic Networks**.

Mobile communication is at present still limited to narrowband applications, in contrast to communication on the wired network. Because the mobile network, as an extension of the fixed network, is continually increasing in both importance and penetration, there is a growing need for broadband mobile channels. The challenge for research is to develop suitable system concepts and coding techniques, to establish the technological principles, 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. 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 project work focussed on **Electronic Imaging Technology for Multimedia.**

At the end of the reporting year, a total of 246 positions were occupied, 148 of which were scientific staff and 98 technical and administrative staff. Of these, 115 positions were in the research area Photonic Networks, 71 in the research area Electronic Imaging Technology for Multimedia, eleven in the research area Mobile Broadband Systems, and 49 in central areas such as management, planning, administration and workshops. At the end of the year there were also seven postgraduate doctoral students, one postdoctoral fellow, eight persons in training, 74 student assistants and four guest scientists working at the HHI.

The Institute's research is financed by both institutional funding, from the Federal Government and the State of Berlin, and external funding. External funding comes mainly from the development concept for information technology of the Federal Government, especially under the research and development programs KomNet, Nano-Optoelectronics (NanOp), INVINET (INTeroperability for VIdeo communication over distributed NETworks), UMTSplus and

ATM*mobil* (Mobile Communication). Further external funding comes from the Fourth RTD Framework Program of the European Union (ACTS, ESPRIT, etc.), from the Deutsche Forschungsgemeinschaft, and from the program for information and communication technology of the Senate of Berlin.

External funding through direct R&D contracts with industry has been of growing importance to HHI, especially as these lead to a stronger orientation of the research topics and methods towards the long and medium term needs of the telecommunication industries. This policy is also consistent with the recommendations in the reviews of HHI by the German Association of Electrotechnical Industries and the German Science Council.

To improve our industrial collaboration in all research areas, a number of new R&D contracts with industry have been entered into, assisted by the Planning and Marketing Department. In addition, many product-oriented small contracts have been obtained from industry, mainly in the areas of photonic components and subsystems, system measurements, electronic imaging technology, and feasibility studies. The institute's participation in technical exhibitions at the major scientific conferences (OFC, ECOC) and trade fairs (CeBIT, Hannover Messe, Internationale Funkausstellung, IBC), and our increased public relations activities in the media, have been particularly helpful in marketing our research products.

In order to better manage the large number of projects and contracts, professional project management and quality management methods (ISO 9000) are now being introduced.

Corporate Bodies

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

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

Prof. Dr. J. Hesse, (chairman), Carl Zeiss, Oberkochen
MinDirig Dr. K. Rupf, (1st vice-chairman), BMBF, Bonn
SenR P. Schuhe, (2nd vice-chairman), SenWissForsch und Kultur, Berlin
MinR J. Claus, Deutsche Telekom AG, Bonn
ORR H.-D. Götze, SenFin, Berlin
Prof. Dr. P. Noll, Technische Universität Berlin
Dr. H. Roehle, HHI, Berlin
Dr. H. Venghaus, HHI, Berlin
MinDirig Dr. W. Berger (guest), BMWi, Bonn

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, (chairman), Technische Universität München
Dr. H. Eisele, Alcatel Kommunikations Elektronik GmbH, Hannover
Prof. Dr. G. Fettweis, Technische Universität Dresden
Dr. R. Gossink, Philips GmbH, Aachen
Dr. H.-G. Junginger, Sony Europe GmbH, Fellbach
Prof. Dr. P. Leuthold, ETH Zürich
Prof. Dr. H. Melchior, ETH-Hönggerberg, Zürich
Dr. B. Schwaderer, Bosch Telecom GmbH, Backnang
Dr. W. Späth, Opto Seminconductors GmbH, Regensburg
Prof. Dr. J. Hesse (guest), Carl Zeiss, Oberkochen
MinR W.-P. Ottenbreit (guest), Deutsche Telekom AG, Bonn
MinDirig Dr. K. Rupf (guest), BMBF, Bonn
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R & D Activities

R & D FIELDS

Photonic Networks

Topics and Results

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

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

These developments will also increasingly affect the customer networks, i.e. the communication networks located in the premises of private or commercial users. As the information has to be transmitted to the user's terminals, the customer network must link these multimedia terminals with the broadband Internet. The prognoses for the year 2010 are data rates of 100 Mbit/s for private and 1 Gbit/s for professional end terminal users.

Since mid-1998, technologies for the future Broadband Internet are being developed and tested in 15 R&D projects under the framework of the German Federal Ministry of Education and Research (BMBF) funding initiative *KomNet – Innovative Communications Networks for the Knowledge-Based Society*. As well as theoretical work and experiments at the various laboratory sites, an experimental communication network connecting the cities of Berlin, Darmstadt, Mannheim and Stuttgart is currently being implemented. This network will provide a platform to assess optical networking technologies, network elements, protocols and subscriber line approaches for the Broadband Internet. The HHI contributes to the KomNet projects through several subcontracts with German industry, including work on the planning of wavelength division multiplexing (WDM) networks, a loop testbed for WDM network elements, ultra high-speed transmission using time division multiplexing, 40 Gbit/s photodetectors, 40 Gbit/s receivers, and transceiver photonic integrated circuits. The HHI Systems Integration Office is also responsible for coordinating the network construction and the field trials.

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

- Development of network concepts for the various layers of photonic networks – the core, access and customer networks
- Investigation of the potential of optical multiplexing techniques such as OFDM and OTDM. The optimum combination of these techniques is of paramount importance.
- Determination of the limits of optical transparency, i.e. the assessment of the transparency path lengths in photonic networks
- Determination of the requirements for the network concepts and the photonic components, including the transmission lines and routing subsystems
- Investigations into the supervision (operation, administration and maintenance – OAM), and the control (Telecommunication Management Network – TMN) of photonic networks
- Investigation of functional linking methods between the physical and protocol layers
- Development of methods and devices for all-optical signal processing for ultra high speed packet routing, signal monitoring and control
- Development and fabrication of photonic components and subsystems

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

Core Network

Work in this research area concentrates on 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 synchronisation of the optical signals are important issues. 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 OTDM work includes the investigation and realisation of optical subsystems such as multiplexers (MUX), which multiplex 10 Gbit/s optical data signals to generate 40 to 80 Gbit/s signals, and demultiplexers (DEMUX), which demultiplex the multiplexed signals. Another important subsystem is the RZ data source, which was realised by a modelocked laser. This data source has been demonstrated in 40 Gbit/s transmission experiments over unrepeatered (no optical amplifiers in the transmission line) transmission spans of up to 150 km of standard fibre. To compensate for fibre dispersion, we applied passive dispersion compensation using dispersion-compensating fibre.

Error-free 80 Gbit/s transmission over 106 km of standard non-dispersion-shifted fibre (D = 16 ps/km/nm) was demonstrated for the first time using mid-span spectral inversion (MISSI) based on four-wave mixing in a semiconductor laser amplifier. The special configuration used allowed very efficient suppression of the pump power without affecting the generated phase-conjugate signals. Accompanying simulations showed that the main limitation was due to second order dispersion, which is also the reason for the performance penalty of about 5 dB with respect to back-to-back measurements.

We performed an experimental comparison of 40 Gbit/s RZ and NRZ transmission over standard non-dispersion-shifted fibre (SMF) under comparable experimental conditions. The RZ modulation scheme enabled error-free transmission over a link length of at least 432 km, whereas the NRZ modulation scheme gave error-free transmission over only 218 km. This advantage of RZ over NRZ transmission is in agreement with theoretical results. The equipment for the 40 Gbit/s NRZ experiment was provided by SHF-Design Mikrowellenkomponenten GmbH, Berlin.

A novel all-optical switch (gain-transparent SOA switch), which has high linearity, high switching contrast, low noise, wide bandwidth and low crosstalk, has been developed and experimentally investigated. The switching principle, which is based on refractive index modulation in a wavelength band far from the gain region of a semiconductor optical amplifier, was successfully applied in a 640 Gbit/s demultiplexing experiment. The project team has been honoured for this fundamental work on high speed switching with the Philip Morris Research Award 1999.

Monolithically integrated nonlinear interferometer switches: The world's smallest monolithically integrated Mach-Zehnder interferometers (device area less than 5x1 mm^2) have been further developed at HHI for all-optical demultiplexing applications. Optical semiconductor amplifiers (SOAs) are used as nonlinear elements in the interferometer arms. The interferometers have been fabricated in two versions. The asymmetric version has a fixed switching window, which is set by the geometrical offset of the amplifiers. The advantage of this structure is its simple control scheme (data and control signals share one input and one output port). In the symmetric version there are two additional branches for the control signals, which allow it to be used for all-optical wavelength conversion, but at the cost of extra control effort (up to 4 optical inputs and 2 optical outputs). Error-free all-optical switching was demonstrated in system experiments with both versions. All-optical demultiplexing from 40 to 10 Gbit/s was achieved with the asymmetric MZI, while with the more flexible symmetric version demultiplexing from 80 to 10 Gbit/s could be achieved with arbitrary choice of the switched channel.

Short-pulse lasers can be realised by using ion implantation to incorporate a saturable absorber, normally in a cleaved facet. To simplify production and to give enhanced design flexibility, a method of "on-wafer" implantation was developed. Q-switched lasers for measurement applications have been fabricated in this way.

Optical devices with switching speeds in the fs region will be required for future transmission systems with OTDM bit rates up to the terabit/s range. InGaAs/InAlAs absorber structures using low-temperature MBE growth are under investigation for this application.

WDM loop testbed for transmission distance measurements: The HHI operates a powerful measurement system for the investigation of the channel degradations along optical paths. Currently WDM transmission systems with up to 16 wavelength channels, each up to 10 Gb/s, can be tested. 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 (OTS) include transmission fibres, optical amplifiers and means for chromatic dispersion compensation. The transmission fibre for 10 Gb/s channels is 80 km standard SMF, and is compensated for dispersion using DCFs.

The goal of testing is to find the optimum configuration and parameters for the so-called normalised sections to be used when a large number of OTSs is cascaded. Such normalised sections are being investigated under a contract with a network operator. Different configurations, with pre-compensation, post-compensation or symmetrical compensation, have been tested with both NRZ and RZ signals. The outcome was a series of charts showing the maximum transmission distances and the corresponding tolerances for the degree of compensation (DoC) and the channel power levels. A maximum distance of 2400 km was achieved with NRZ signals, symmetrical compensation of the chromatic dispersion, and a DoC of 99%. A systematic comparison of other types of normalised sections is still in progress.

Instead of DCFs, chirped fibre Bragg gratings could be used for dispersion compensation. First measurements indicate that these gratings are inferior to DCFs with respect to bandwidth and ripples in amplitude and phase.

The channel rates of the loop testbed will be increased to 40 Gb/s in a new project.

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

A preliminary conclusion from the measurement results so far is that transparent optical network domains with path lengths of the order of 1000 km can be achieved.

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

Network planning tools are the subject of a contract with a system provider. The attempt is to create "reference circuits" using the ITU-T sections and elementary network configurations, which can be used as building blocks for all kinds of network topologies. Ring networks are of great practical importance due to simple protection switching schemes. Different topologies for unidirectional and bidirectional rings with two and four fibres have been analysed for normal and protection mode operation. First simulation results of a simple two-fibre ring with four add-drop nodes fully meshed through 40 Gb/s WDM channels using standard SMF indicate its suitability for metro rings up to 60 km perimeter without in-line amplifiers.

Larger rings with more nodes and higher channel rates require novel components and topologies. Promising methods for realising large rings are distributed Raman amplification, which is being investigated in another DFG project, and novel single mode fibres, which are to be developed and tested in a planned cooperative effort between HHI and an industrial partner.

Signal regeneration: Scalable networks need full "3R" (reamplification, reshaping, retiming) signal regeneration. Components and methods for this application are under development. Optical clock recovery is performed using self-pulsating DFB lasers. These three-section devices are controlled by three dc currents, which switch the self-pulsation on and off and tune its frequency. Very large (two octave) tuning ranges and frequencies of more than 40 GHz have now been achieved. The self-pulsation synchronises to optically injected data signals, and thus realises all-optical clock recovery.

In cooperation with Alcatel, a full 3R regenerator has been assembled using the self-pulsating laser as the clock and a Mach-Zehnder Interferometer as the decision element. This regenerator was tested in loop experiments, with the loop comprising 50 km of dispersion-shifted fibre (DSF), fibre amplifiers and the 3R regenerator. The bit error rate (BER) was measured after the signal had traversed the loop a number of times. Even after 300 circuits (equivalent to a 15,000 km transmission path) there was no increase in the BER. This demonstrates that the all-optical 3R regenerator is very effective at suppressing the accumulation of noise and jitter.

Modified multi-section lasers have been developed that have bistable switching characteristics instead of self-pulsations. These devices have already been applied for wavelength conversion with 10 Gb/s RZ signals, and experiments using them as clocked decision elements are currently in progress.

Network modelling: Methods for simulating optical components and signal propagation in an optical path are being developed, and are being checked by comparison with the experimental measurements. As well as the programs we have developed ourselves, we also use the commercially available program package PTDS (from Virtual Photonics Inc., a spin-off of HHI). With the transmission line laser model it is possible to optimise photonic components and subsystems, such as the 3R regenerator and the nonlinear Mach-Zehnder Interferometer (used as a very fast optical gate).

The work towards high bit rate TDM and the combination of TDM and WDM technologies is also supported by analytical and numerical investigations, the main question being how to set up the transmission line to achieve optimum transmission capacity.

High speed photodetectors and receivers: As part of the joint project KomNet, InP-based optoelectronic integrated circuits (OEICs) are being developed for the reception of high bitrate data streams in TDM transmission systems. They consist of waveguide-integrated PIN photodiodes and MMIC-type electrical amplifiers using high electron mobility transistors fabricated by e-beam lithography. A flat transfer function with less than ±1 dB ripple up to the 3 dB bandwidth of about 40 GHz was achieved. The receiver OEICs, packaged as modules, were used in system experiments by industrial partners for the detection of 40 Gbit/s signals modulated in RZ and NRZ formats, and will soon be used in field trials.

Photodetectors based on InP are also being developed for the KomNet project. These can operate at large optical input powers and can directly drive a differential digital demultiplexer IC at large data rates. For this purpose, two waveguide-fed PIN photodiodes in differential mode configuration, an optical 3 dB power splitter, a spot-size transformer at the waveguide input port, and biasing circuitry were monolithically integrated. The inclusion of the spot-size converter led to an increased conversion efficiency of 0.5 A/W. Very uniform frequency behaviour of the two photodiodes was obtained, with less than 2 dB difference between the RF output powers over the entire bandwidth of more than 50 GHz. Eye pattern measurements performed by the industrial partner proved its suitability for 40 Gbit/s transmission systems.

Access and Customer Network

Research and development activities in this area was concentrated on the use of WDM techniques in the access network. Specifically, the goal was to develop and investigate system concepts and components for WDM applications in the access network.

Local DWDM networks for IP traffic: Current optical networks use only point-to-point optical transmission, with switching and routing still done in the electronic domain. Using DWDM (dense wavelength-division multiplex) technology it is possible to obtain higher functionality in the optical layer of the network.

DWDM technology supports a large number of channels with different wavelengths. Terabit DWDM transport networks with up to 128 channels and channel spacings from 100 to 400 GHz have already been demonstrated by the industry.

In a project that was completed in 1999 we have developed and demonstrated the upgrade of a PON (passive optical network) using additional DWDM channels. Based on this work, future local DWDM networks may be designed that are optimised for the unique characteristics of Internet traffic. Components for these networks are being developed and characterised. The objective of this work is to use flexible allocation of DWDM channels to improve the network configuration dynamics and scalability so that it better matches the bandwidth requirements of the subscribers.

We investigated the requirements for the optical transmitters and filters in DWDM networks, including whether already available components can be used. A beginning was made on designing and developing receivers for synchronous and asynchronous transmission in DWDM networks.

We also began to examine how to design DWDM networks that are optimised for Internet traffic, as well as the consequences for the optical transmission layer of omitting redundant functionalities in current multilayer networks, such as IP over combinations of ATM, FR or SDH.

Monolithically integrated transceivers: Bidirectional optoelectronic transceivers are being developed for access network applications. The crucial importance of WDM transceiver photonic ICs (PICs) for optical access networks has been emphasised by the Full Service Access Network (FSAN) Group as well as in the Japanese OITDA report. This project is being carried out in close collaboration with industrial partners. The fabrication cost of high volume optical modules is expected to be reduced by the implementation of photonic ICs. The main issues of this project are:

- The ongoing development and availability of a technological toolbox for the flexible and economic integration of basic optical and optoelectronic building blocks (e.g. lasers, waveguide networks, photodetectors), without essential loss of performance compared to separately fabricated elements
- The application of this technology for the realisation of complex PICs
- The demonstration of the functionality of a monolithically integrated polarisation-insensitive heterodyne receiver
- The extension of the versatile integration technology for the fabrication of WDM transceiver PICs (the first high volume candidates)
- The processing of 1.3/1.5 µm transceiver PICs meeting the system requirements

This year's activities on the 1.3/1.5 µm transceiver development focussed on the economic fabrication of the integrated subcomponents (integrated ridge-waveguide DFB laser, integrated photodiode including an absorber for 1.3 µm light, low loss Y-junction combiner/splitter, and integrated optical field transformer). Based on these results, the next step will be the fabrication of the first completely integrated transceivers.

Lasers for WDM: Optical transmitters in WDM systems must cover a number of adjacent channels, usually spaced according to the ITU grid. This functionality can be realised by laser arrays, with each laser serving an individual channel. Such devices have been monolithically integrated on InP and have been delivered as prototypes to various small and mid-size companies. In return HHI has received important data from device tests related to actual applications. Our customers especially valued the relatively large output powers, the excellent aging characteristics and the reliability of our lasers.

Work has commenced on using GaInAsN as the active material in GaAs-based structures. This promises to be useful for both 1.3 µm high temperature lasers and vertical cavity devices (e.g. VCSEL). QW layers with intense emission at 1.3 µm were successfully grown.

WDM filter components: Work on silica-based arrayed waveguide grating (AWG) filters has been continued by fabricating devices with up to 32 channels with a separation of 100 GHz. The insertion loss of pigtailed devices was below 5 dB, and the crosstalk was less than -27 dB. "Flat-top" structures were also investigated. Polarisation dependence were largely eliminated by employing stress compensated silica layers developed by a collaborating partner.

The development of a special AWG component that makes it possible to overlay an existing passive optical network (PON) with a WDM network has been extended to a novel, more compact design, which is the subject of a patent application. The new device incorporates an integrated star coupler to split the PON broadcast signal.

AWG devices were also implemented on low loss (0.3 dB/cm), high thermal stability (>250°C) polymer material synthesised by the Teltow branch of the Fraunhofer Institute IZM. Devices with up to 32 wavelength channels were fabricated.

A new approach for implementing optical switches is being pursued by combining low loss silica waveguides and vertically coupled, thermo-optically controlled polymer waveguides. First digital optical switches realised in this way could be demonstrated.

Competencies

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

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

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

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

Development of methods for the control and supervision of networks.

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

Design and development of optical systems using heterodyning.

Development of wavelength conversion methods for WDM systems.

Investigation and development of high rate OTDM subsystems (40 to 80 Gbit/s and above), including multiplex/demultiplex and add/drop techniques.

Development of methods for purely optical clock recovery and signal regeneration (2R and 3R).

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

Optimisation of methods of dispersion management.

Design and development of optical frequency reference equipment.

Design and fabrication of transponders and optical SDH front ends.

Development, fabrication and characterisation of fibre optic components.

Development, fabrication and characterisation of methods and devices for PMD compensation.

Development, fabrication and characterisation of opto-electrical components and photonic integrated circuits based on InP:
- Tunable lasers (DFB, DBR)
- Multi-wavelength laser arrays
- Optical amplifiers
- Fast laser/modulator transmitters
- Wavelength converters
- Demultiplexers and add/drop multiplexers for OTDM applications
- Components for optical clock recovery and signal regeneration (self-pulsating lasers)
- Integrated transceivers
- Fast photodiodes with high optical power
- Differential mode photodetectors (twin photodiodes)
- High bitrate optical receivers with integrated MMIC preamplifiers
- Optic/microwave converters
- Spot-size transformers for optical waveguides.

Development and fabrication of thermo-optical switches and switch matrices with minimal crosstalk using polymers.

Development and fabrication of planar waveguide components in SiO_2/Si (e.g. waveguide grating filters).

Development and fabrication of passive and of electrically controllable diffractive optical components in SiO_2.

Modelling of photonic components, photonic subsystems and integrated circuits.

Development, optimisation and application of component technologies:
- Clean room laboratories (class 10/1000)
- Epitaxy (MOVPE, MBE, MOMBE) and the characterisation 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
- 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
- Characterisation and technology of optical polymer materials
- Chip mounting and connection techniques
- Fibre-chip coupling
- High-frequency packaging.

Mobile Broadband Systems

Topics and Results

In recent years personal and mobile communications systems have experienced an overwhelming increase in the number of users. This, together with the introduction of additional services such as data transmission, has lead to a growing need for capacity. Capacity can be increased by higher spectral efficiency. Several techniques are being developed to do this. In a cellular system the capacity is limited by the cell density, the frequency reuse distance and the number of users who can be served simultaneously by each base station.

Smart antenna technology is one of the most significant new techniques for increasing the capacity of mobile networks. It has a great impact on the radio performance – e.g. it decreases the bit error rate in the uplink channel (the link from the mobile unit to the base station) in CDMA cellular radio systems.

Future mobile communications systems are also facing an increasing demand for heterogeneous broadband services and applications. Smart antennas will not only increase the capacity of the system, but they also reduce interference and delay spread by means of spatial filtering, thus enhancing the properties of the mobile radio channels, as required for high data rate communications. Although it is generally expected that smart antennas will be used in emerging third generation communication systems such as UMTS/IMT-2000, the design of fourth generation systems such as the Integrated Broadband Mobile System (IBMS) is based completely on smart adaptive antenna technology, which allows the use of more advanced bandwidth-efficient modulation schemes. The IBMS project is sponsored by the German Federal Ministry of Education, Science, Research and Technology (BMBF).

The performance enhancements that can be achieved with constrained beamformers in code division multiple access (CDMA) cellular radio systems were investigated in connection with IBMS. Our investigations focussed on improving the reverse (uplink) channel, the main problem with such systems. The analytical results and simulations demonstrate that constrained beamformers at the base station can dramatically improve the reverse channel bit error performance.

To achieve optimal system performance, a new constrained beamforming algorithm was proposed. Whereas existing beamformers allow only the directions of either the zeros or the main beam to be controlled, the new beamforming algorithm allows the control of both. The number of zeros in the beam pattern that can be constrained depends on the number of sensors in the array antenna. This new constrained beamforming algorithm can produce an optimised beam pattern that exploits both space division multiple access (SDMA) and spatial filtering for interference reduction (SFIR).

The 2D rake receiver is a promising means for improving the characteristics of a radio channel with frequency-selective multipath propagation. It combines two signal processing concepts: temporal equalisation and co–channel interference (CCI) reduction. Based on the above beamforming algorithms, a new space-time processing framework has been developed that rejects both MAI (Multiple Access Interference) and ISI (Inter Symbol Interference) to maximise the signal-to-noise-plus-interference ratio (SNIR).

The radio frequency properties of the antenna array must be known if array signal processing methods are to be used in mobile communications systems. We have investigated experimental antenna arrays to determine and model these properties. The results have led to an extension of the new beamforming algorithm that can now be applied to calibrated real antenna arrays.

The propagation conditions in indoor environments, where many echoes arrive from different directions, are more difficult than in outdoor environments. Due to the large number of echoes and their angular spread, it is not practical to eliminate the interfering signals by aligning the zeros of the beam pattern with the directions of these signals. A new constrained beamforming algorithm for indoor applications was introduced to generate an optimal beam pattern for indoor environments with many echoes, allowing for their angular distributions.

The future mobile communication systems of the fourth generation will support higher data rates than current systems. Because of higher data rates the carrier frequencies will also increase, leading to a decrease of cell size. The mobility behaviour of the subscribers is a factor that cannot be ignored with small cell sizes, since the performance of mobile communication systems depends strongly on the mobility and calling behaviour of the subscribers. New mobility models were proposed to describe the movements of the subscriber at different scales. These new mobility models can be used to estimate the cell and location area crossing rates, and hence the amount of mobility-related signalling, such as handover and location update signalling. The new models are extensions of the ETSI (European Telecommunication Standards Institute) mobility models.

Another research area in the indoor domain focuses on infrared and microwave communications.

For wireless infrared (IR) communication, two approaches are presently under investigation that exploit directed beam line-of-sight and spot diffusing links. The aim is to realise inexpensive and power-efficient transceivers for data rates up to 155 Mbit/s. Both base station oriented systems and ad hoc LAN systems with spot diffusion but no base stations are under consideration. The system performance and power budget are considerably improved when directed links are used which are controlled to keep the beams between the base and the mobile station aligned. Array technologies for the receiver and transmitter will supersede the use of mechanically moved optics and will allow a single interface for narrowband and broadband services.

Laboratory experiments on an IR ad hoc LAN were carried out at a wavelength of 1.55 μm. The distribution of the transmitter power across the cell was realised by diffuse reflection from the ceiling (spot diffusion with diffusion angle about 100 degrees). The receiver optics, with field of view less than one degree, was directed towards the diffusing spot. Error-free digital video transmission at 140 Mbit/s with CMI coding could be obtained in a 20 m^2 cell with 5 mW transmitter power in a collimated beam, which is safe for the human eye for wavelengths greater than 1.4 μm.

Smart antennas in the 60 GHz range will play an important role in future mobile communication systems at data rates of 155 Mbit/s. The generation and distribution of the microwave signals will be carried out using optical microwave technology, which allows the realisation of simple base stations in the picocellular network. The required microwave signals, with low phase noise and quartz stability, will be generated using the optical heterodyne principle and modulation sideband injection locking. First fundamental experiments have been successfully carried out, and will be continued as part of a planned project. The beamformer components and the beam steering algorithms will also be tested in an experimental system.

The optical transmission technique is already used in the area of phased array antennas to take advantage of the broadband and low loss properties of optical fibres. Further advantages of optical methods, especially for space-borne antennas, are the low weight and compactness of the fibres. For the control of phased array antennas, the distribution network connecting the central electronics with the antenna elements should have low loss and high phase stability.

The properties of switchable optical delay lines were investigated under a contract with industry. These delay lines can be used for beamforming by controlling the phase relations between the antenna elements. The beamforming network was controlled using semiconductor optical amplifiers at 1.3 μm as switching gates. These gates have nanosecond switching speeds and large on-off ratios for the microwave signals. This investigation is now complete.

Electronic Imaging Technology for Multimedia

Topics and Results

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

Image Processing

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

As far as hardware projects are concerned, the development of architectures for future multimedia terminals is the central activity, with the focus on key components for 3D graphics, compositing, MPEG encoding and decoding, and format conversion. One emphasis is on Interoperability for Video Communication over Distributed Networks (INVINET), which is a collaborative project sponsored by BMBF. The main topics of this project are the development of basic technologies for IP-based video communication, especially for mobile networks, and of interactive services over these networks, particularly those using virtual environments. Important topics are the new compression standard H.26L, which is being developed in ITU-T, the development of an authoring tool based on MPEG-4 for the creation of 3D scenes, and a 3D compositor for MPEG-4.

- A DSP module was developed to implement a real-time MPEG-4 decoder. This module consists of a signal processor, a co-processor for bit-stream decoding, and memory. This device was connected to a flat LCD display to realise a prototype for a mobile MPEG-4 terminal. The complete decoder/display system was exhibited during the BMBF status seminar "Mobile Communication" in Berlin.
- As a result of its work on H.26L coding, HHI has submitted it's own proposal to ITU-T for standardisation. This proposal is based on the wavelet transform and warping prediction.
- A first version of a 2D compositor for MPEG-4 has been developed. This allows the manipulation of 2D video objects on the screen, i.e. the shift, rotate and zoom operations. This compositor was exhibited during the BMBF status seminar "Mobile Communication" in Berlin.

Based on the current status of image coding (MPEG-4, BIFS) and of description languages for interactive services (HTML, VRML, JAVA), concepts for the coding, transmission and presentation of interactive video and VR applications are being developed in close co-operation with service providers. The main goal is to define new object-oriented, graphics-oriented and video-oriented user functions that take into account both these standards and the constraints due to production technology and transmission characteristics. These user functions will be presented to producers and service providers in order to demonstrate their attractiveness and feasibility. Services such as home shopping, business TV and virtual communication platforms are used as examples to show the potential of these new technologies. Tools will also be made available for new interactive services. Image segmentation techniques, which can be used either on-line or off-line, are important tools for such applications and are therefore being developed at HHI.

- A prototype of the world's first distributed virtual video conference system has been further developed and was presented to the public during the World of Consumer Electronics (IFA '99). This system allows four subscribers to be connected via ISDN or LANs for a video conference. The images of the three other participants, who are encoded with MPEG-4 in their natural shapes, are shown in an artificial 3D conference environment, through which the viewer can navigate. An important feature of this system is a real-time segmentation tool that can separate the participants from an arbitrary background.
- The "Incomplete 3D System", which was developed and patented at HHI, has been optimised for real-time operation in order to integrate it into the virtual conference system. Incomplete 3D uses a stereo camera setup and a very elegant and simple method of 3D image synthesis.
- IMANA, a software package for interactive image segmentation, has been developed.

This software includes tools for contour generation, temporal prediction, automatic contour adaptation, semi-automatic contour correction, contour tracking, error recognition and key generation. IMANA has been presented at several conferences and was exhibited at the International Broadcast Convention (IBC '99) in Amsterdam.

The development and verification of technologies that are required for new functionalities in mobile multimedia systems is of crucial importance. Such functionalities have been identified in ISO-MPEG, and the MPEG-4 standard will be the basis for image and sound compression in future multimedia systems. These new functionalities, including content manipulation, content-based scalability and content-based access, are obtained with coding algorithms that are both very efficient and robust against transmission errors. New methods of data communication between terminals based on generic languages are also being developed as part of this framework.

- HHI has realised a number of software implementations of MPEG-4 encoders and decoders. These serve as reference models for hardware developments and are also used in real-time applications based on MPEG-4, and have been applied by several industrial partners. HHI is also responsible for the integration of the MOMUSYS reference model, which is one of the two official test models of MPEG-4, alongside the Microsoft version.

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

- The search engine developed by HHI allows searching for images of similar content in an image data base. Description parameters based on contour, texture and colour information may be used. HHI has been very successful in the MPEG-7 standardisation process, where several of its proposals have been accepted.
- A demonstrator has been developed in the ACTS project CustomTV that allows for the transmission over DVB channels of MPEG-4 and MPEG-7 data along with MPEG-2 programs. MPEG-4 data may be used to interactively retrieve items such as trailers for movies, weather charts or stock information, while the MPEG-7 data is used to alert the user to certain events in other programs or to assist program selection according to the user's preferences. This system was presented to the public during the International Broadcast Convention (IBC '99) in Amsterdam.

HDTV is currently gaining increased attention. Although HDTV broadcast services using MPEG-2 coding have already been introduced in the US and will be introduced in Japan in 2000, the applications being considered in Europe are mainly in niche areas, such as electronic cinemas, advertisements or in medicine. The MPEG-2 standard, which allows the transmission of HDTV material at about 20 Mbit/s, will be used worldwide for this purpose.

- HiPEG, one of the world's first functional single-chip decoders for HDTV that implements the Main Profile @ High Level of MPEG-2, was developed at HHI. MikroM GmbH, a spin-off company from HHI, has since developed a second generation chip HiPEG+, which provides increased functionalities, as well as the new decoder boxes HiBOX 2 and HiBOX 3. HiBOX 2 was presented to the public at various exhibitions jointly with HHI, including NAB '99 (USA), IFA '99 (Berlin) and IBC '99 (Amsterdam).
- In order to display stereo images on commercial 100 Hz TV sets or on the autostereoscopic display described below, a special decoder (HiBOX) was developed. This unit allows the simultaneous and synchronised decoding of two MPEG-2 encoded bitstreams, such as the left and the right channels of a stereo pair. These signals can be obtained from a DVD drive using a SCSI interface or from a DVB channel using a parallel DVB interface. Live DVB-T transmissions of Stereo TV were presented to the public during IFA '99.

Interactive Media – Human Factors

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

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

The autostereoscopic display developments concentrate on approaches that do not require the user to wear special glasses when viewing natural or computer generated 3D images or videos. Applications of this technology are in the areas of 3D telephony and video conferencing, 3D TV, 3D multimedia desktop computing, 3D virtual worlds, telepresence and telework, telesupervision, vehicular technology, CAD/CAM, 3D computer games, medicine, and biology. The work in this area includes the development of small to large flat panel autostereoscopic displays for one or more viewers, as well as large format front or back projection displays using either lenticular array screens or field lens technology. Prototypes of these developments were introduced to the public this year and last at many trade fairs and exhibitions.

• An autostereoscopic 14" flat display panel using lenticular array screen tracking was developed jointly with the firm Zeiss, Oberkochen, who also licenced the technology of lenticular screen tracking.

• A high resolution single-person autostereoscopic 15.1" flat panel display ((2x512)x768 pixels) for use in the CAD/ CAM area was developed. This does not require mechanical tracking of the lenticular screen – instead, the monitor is mounted on a mechanical tracking platform so that the image plane can track the user's head movements.

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

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

• A flat wide-screen 42" 16:9 autostereoscopic display for multiple users was developed. It combines a plasma display of 852x480 pixels with a lenticular plate. With a stationary lenticular plate at least three viewers can see spatial images simultaneously. Alternatively, the viewing condition can be made more comfortable for one viewer by using a tracked lenticular plate, controlled by video-based head tracking.

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

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.

A first 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, and simple means for the user to interact with it. In contrast to conventional windows-based desktops, the new operating system is object oriented and can stack information in the depth dimension.

• A 50" high resolution autostereoscopic display that was developed at the HHI was used for the prototype of a 3D computer that allows the visualisation of multimedia objects arranged in the depth dimension. These objects are generated and managed by the 3D operating system. Because of the autostereoscopic representation, the user can see the objects and information stacked in depth layers, and can view them from different sides by moving his or her head (movement parallax).

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

• 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 '99 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 position, and a system to determine the gaze direction (for gaze-controlled interaction).

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

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

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

• An algorithm for object segmentation of trinocular images was developed for applications in 3D desktop computers. This algorithm can decompose image objects into depth layers and makes it possible to recognise people and spatial structures in images. This information can be used for depth-oriented representations of images and videos, with the depth of focus matched to the human visual system if the viewer's gaze direction is measured at the same time. It can also be used by an intelligent and 'seeing' computer that is equipped with a trinocular camera system to distinguish and recognise spatial structures (e.g. people, hands, physical objects) in its neighbourhood – in appropriate cases it could then act autonomously.

• New representations of objects in space were investigated and optimised in a series of psycho-optical experiments, in order to extend the ways in which 3D images can be represented in autostereoscopic multimedia displays, while still maintaining compatibility with the human eye. By measuring the fixation point of the viewer, using gaze direction measurements, the depth of focus of the stereo pair is changed by digital filtering so that it matches the natural depth-of-focus behaviour of the human eye (synthetic depth of focus).

The development of operating concepts that will be needed by the users of future multimedia TV is being carried out as part of the BMBF joint project MINT (Multimedia on Integrated Networks and Terminals). The aim is the development of prototype TV receivers that integrate many multimedia applications. A central challenge, apart from the integration of services, is the way they are operated and the guidance available for the user; these must be simple and user friendly because of the complexity of the services.

• A prototype of a multimedia TV set was implemented. This gives the user typical Internet services (e.g. email, www, home shopping) and new communication services (e.g. video telephony, digital audio broadcasts – DAB, MPEG-4 virtual conferencing) as well as conventional television.

• A user desktop, which was developed by rapid prototyping after user tests, gives the user simple and easily understandable control of all the services integrated into the TV receiver.

A further major research area was the investigation of communication systems with a high degree of telepresence. Concepts were developed and demonstrated in the laboratory, and also empirically checked by means of user tests. 3D imaging techniques were shown to be useful for increasing telepresence and effectiveness in communication experiments with studio video conferences at the HHI. Similar advantages are expected for workplace conferences, and generally for workplace systems. Since this style of communication will increase in importance, the use of 3D technology in workplace systems was also investigated. In this case the main considerations were the undistorted reproduction of movement parallax, the perceptually conflict-free mixing of 2D and 3D images, and user friendly remote pointing in stereoscopic images.

• Following investigations, guidelines for applications that include modelling of movement parallax were developed to include a mechanism for the viewer to adjust the relation between changes of the perspective centre of the image and changes of head position.

• Based on user investigations, rules for mixing 3D images were developed to avoid disturbing artifacts in the picture plane.

• An autostereoscopic workplace display using field lenses was developed that separates the stereo images using directed light. It features bright stereo images with good contrast that are easily viewed, even with the lighting conditions in office workplaces.

Informal communication is an important aspect of human communication. This includes spontaneous and mostly confidential conversations, e.g. on the fringes of conferences, during coffee breaks or at other chance meetings. Since this form of communication has a positive significance for the individual worker as well as for the organisation, means of providing technical support for informal communication among distributed work groups (for either telework or telecooperation) are being sought. 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.

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 standardisation 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.

Competencies

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

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

Image segmentation, feature extraction and classification.

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

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

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

Development and design of integrated circuits for image processing.

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

Development of 3D display technologies.

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

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

Development of video-based pattern recognition and photogrammetry methods.

Modelling and development of integrated circuits for image processing.

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

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

Expertise in desktop computer graphics design.

Development of diffractive optical components for read/write heads for optical disks.

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
System Studies and the Test of Components for City Ring Networks	Ernst-Jürgen Bachus +49(0)30-31002-586 bachus@hhi.de	BMBF/Industry (KomNet) 9/98 – 12/99
Planning Guidelines for WDM-Systems in City- and Access Networks	Ernst-Jürgen Bachus +49(0)30-31002-586 bachus@hhi.de	BMBF/Industry (KomNet) 1/99 – 12/99
Performance Monitoring of WDM Channels	Ernst-Jürgen Bachus +49(0)30-31002-586 bachus@hhi.de	DFG 6/99 – 0/01
DWDM and IP	Jügen Saniter +49(0)30-31002-288 saniter@hhi.de	HHI 10/99 – 12/02
Micromachined Tunable WDM-Receiver	Thomas Hermes +49(0)30-31002-546 hermes@hhi.de	DFG 8/99 – 3/01
40 Gbit/s OTDM for KomNet	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.de	Industry/ KomNet 7/99 – 4/02
Optical Time Domain Multiplex Technique for the Internet of the Future	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.de	BMBF 8/99 – 7/02
Optical Sampling of High Bitrate Data Signals	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.de	DFG 6/98 – 5/00
Gain-Clamped Optical Amplifier in Fibre-optical Transmission Systems	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.de	DFG 4/98 – 3/00
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 7/98 - 6/00
Development of BH-Laser	Martin Möhrle +49(0)30-31002-724 moehrle@hhi.de	HHI 4/99 – 12/00

Multiple-Quantum-Well-Laser	Jochen Kreißl +49(0)30-31002-525 kreissl@hhi.de	State of Berlin 7/97 – 12/00
Four-Wavelength WDM Transmitter Chip	Frank Fidorra +49(0)30-31002-707 fidorra@hhi.de	HHI 1/98 – 12/99
Development of an Integrated Multi Channel Transmitter	Frank Fidorra +49(0)30-31002-707 fidorra@hhi.de	Industry 10/98 – 1/99
Four-Wavelength DFB Laser Array Chips	Frank Fidorra +49(0)30-31002-707 fidorra@hhi.de	Industry 1/99 – 6/99
Picosecond Laserdiode System	Anagnostis Paraskevopoulos +49(0)30-31002-527 paraskevopoulos@hhi.de	State of Berlin 11/98 – 1/00
Developmen of Laser Diodes for Gas Analysis	Anagnostis Paraskevopoulos +49(0)30-31002-527 paraskevopoulos@hhi.de	Industry 1/99 – 6/99
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Electroabsorption Modulated DFB-Laser Diodes (EML)	Ludwig Mörl +49(0)30-31002-276 moerl@hhi.de	HHI/Industry 1/99 – 4/00
InP-Based Micro-Mechanical Tunable and Selective Photo-detector for WDM-systems	Harald Künzel +49(0)30-31002-546 kuenzel@hhi.de	TH Darmstadt 1/97 – 12/99
Demonstrating Evolution of Metropolitan Optical Network	Herbert Venghaus +49(0)30-31002-555 venghaus@hhi.de	EU 1/99 – 12/99
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
Development of Twin Photodiode-Photoreceivers for a 40 Gbit/s TDM Field Experiment in KomNet	Andreas Umbach +49(0)30-31002-526 umbach@hhi.de	BMBF/Industry (KomNet) 5/98 – 4/02
40 Gbit/s Photoreceiver Module Development for the GIGATRANS-PORT Field Experiment in KomNet	Heinz-Gunter Bach +49(0)30-31002-503 bach@hhi.de	BMBF/Industry (KomNet) 6/98 – 5/01
40 Gbit/s Frontend Development for an ETDM Long Haul Trans-mission in KomNet	Heinz-Gunter Bach +49(0)30-31002-503 bach@hhi.de	BMBF/Industry (KomNet) 6/98 – 5/01

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Ultra-fast Photodetectors for Optoelectronic Characterization Techniques	Udo Niggebrügge +49(0)30-31002-550 niggebruegge@hhi.de	State of Berlin, IBB 1/99 – 5/00
All-optical Signal Processing	Bernd Sartorius +49(0)30-31002-508 sartorius@hhi.de	Industry 1/98 – 12/00
Design of Switching Characteristics in Dispersive Q-switch Semiconductors	Bernd Sartorius +49(0)30-31002-508 sartorius@hhi.de	Industry 1/98 – 12/00
REgeneration of Pulse shapE, Amplitude and Timing, REPEAT	Detlef Hoffmann +49(0)30-31002-454 hoffmann@hhi.de	EU 3/98 – 2/00
Nonlinear Interferometer Photonic Integrated Circuits for all Optical Demultiplexing in OTDM Systems	Michael Schlak +49(0)30-31002-407 schlak@hhi.de	Industry 1/98 – 12/00
Semiconductor Saturable Absorber Structures for Femtosecond Demultiplexer	Harald Künzel +49(0)30-31002-546 kuenzel@hhi.de	MBI/HHI 11/98 – 10/01
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Polymeric Optical Waveguide Enhanced Router (POWER)	Norbert Keil +49(0)30-31002-590 keil@hhi.de	Industry 2/98 – 1/00
Planar Optical SiO_2 / Polymer Switch Matrix	Norbert Keil +49(0)30-31002-590 keil@hhi.de	Industry 3/98 – 2/00
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Diffractive Optical Elements for a Write/Read Optical Pickup of a Disk	Berndt Kuhlow +49(0)30-31002-448 kuhlow@hhi.de	TH Darmstadt 10/96 - 12/99
Next Generation Colour Electroluminescent Displays, ESPRIT ELDISP	Karl-Otto Velthaus +49(0)30-31002-645 velthaus@hhi.de	EU 11/96 - 10/99

Active Matrix Electroluminescence (AMEL)	Karl-Otto Velthaus +49(0)30-31002-645 velthaus@hhi.de	Industry 1/98 – 12/99
Mobile Broadband Systems		
Software Radio Based Access System – SORBAS	Holger Boche +49(0)30-31002-540 boche@hhi.de	Industry 4/99 – 5/01
Uplink-Space-Time Array Processing for 3G WB/CDMA	Holger Boche +49(0)30-31002-540 boche@hhi.de	Industry 9/99 – 7/01
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Electronic Imaging Technology for Multimedia		
Interoperability for Video Communication over Distributed Networks, INVINET	Guido Heising +49(0)30-31002-226 heising@hhi.de	Industry 1/99 – 3/02
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Coding of Contour- and Surface Data Using Wavelets	Jens-Rainer Ohm +49(0)30-31002-617 ohm@hhi.de	DFG 10/97 – 9/99
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Intelligent and User-adaptive Systems for Navigation and Retrieval of Images	Thomas Meiers +49(0)30-31002-218 meiers@hhi.de	BMWi 1/99 – 12/01
A Communication Platform for Informal and Computer Supported Communication in	Lothar Mühlbach +49(0)30-31002-237 muehlb@hhi.de	BMWi 1/99 – 12/01
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Selected Contributions

KomNet – Innovative Communication Networks for the Information Society

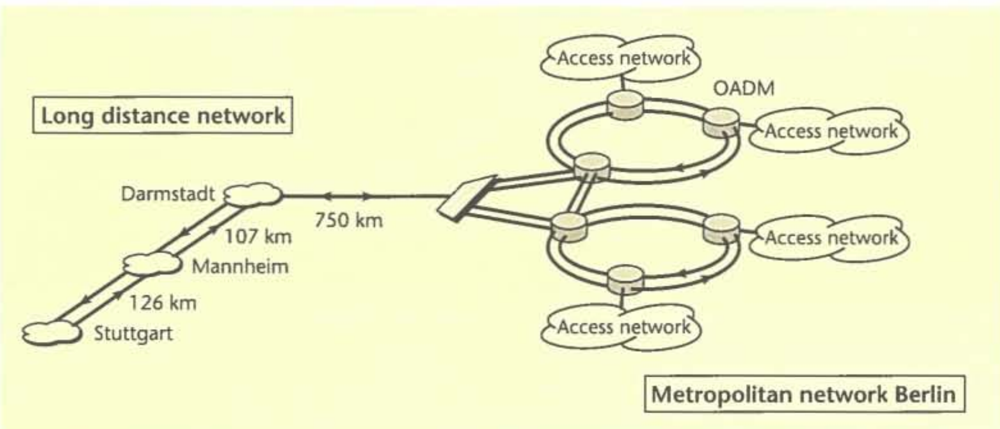
KomNet incorporates a national-scale DWDM (Dense Wavelength Division Multiplexing) platform that will serve as an infrastructure for research and experiments on the Next Generation Internet. After about one and a half years of preparatory work, the industry-based KomNet consortium is about to put together ultra-high capacity WDM and high-speed TDM transmission systems, including all the key components needed for setting up advanced communication networks. HHI contributes to KomNet with several R&D projects and the Systems Integration Office.

The world-wide explosion of data traffic, together with growing customer expectations of the Internet and other multimedia services, leads to new performance requirements for future communication networks. Under the framework of a research initiative guided by the German Federal Ministry of Education and Research (BMBF), a national-scale optical transport network is being established to provide a platform to assess optical networking technologies, network elements, protocols, and subscriber loops [1]. One of the major goals of KomNet is to develop and demonstrate advanced broadband technologies for the Next Generation Internet [2]. All essential segments of this testbed configuration, which comprises long-haul systems, metropolitan networks and access networks (see the figure), will be prototyped and proved under real-life environmental conditions.

Most of the conceptual work for the field trials is finished. The partners will set up these trials using an existing conventional standard single mode fibre infrastructure spanning more than 1000 km. The consortium work includes the submission of significant findings to the international standardisation bodies.

HHI contributes to KomNet as a subcontractor to the industry consortium, with projects on WDM network planning, the evaluation of network elements, ultra high-speed TDM transmission, 40 Gbit/s photodetectors and receivers, and transceiver PICs (cf. subsequent sections). Also, the KomNet Systems Integration Office at HHI oversees the implementation of the demonstration network and the realisation of the field trials, and has both technical and organisational roles.

The Systems Integration Office was supported by the industrial partners, and was funded partly by the German Ministry of Education, Science, Research and Technology under grant number 01 BP 805.



KomNet field trial topology

An industry-based consortium, consisting of Alcatel SEL, Bosch Telecom, Deutsche Telekom Innovationsgesellschaft (T-Nova), Infineon Technologies, Lucent Technologies, Robert Bosch and Siemens, is cooperating closely with 16 universities, research institutes and a small enterprise in 15 projects over the years 1998 to 2002. The project budget amounts to € 60 million, with a 50% cost share between BMBF and the consortium.

[1] K.-D. Langer, G. Walf and J. Vathke, "KomNet – A modular platform to assess optical networking techniques and components", A. Bononi (Ed.) Optical Networking, Springer Verlag 1999, pp. 48-51.

[2] http://www.hhi.de/komnet/

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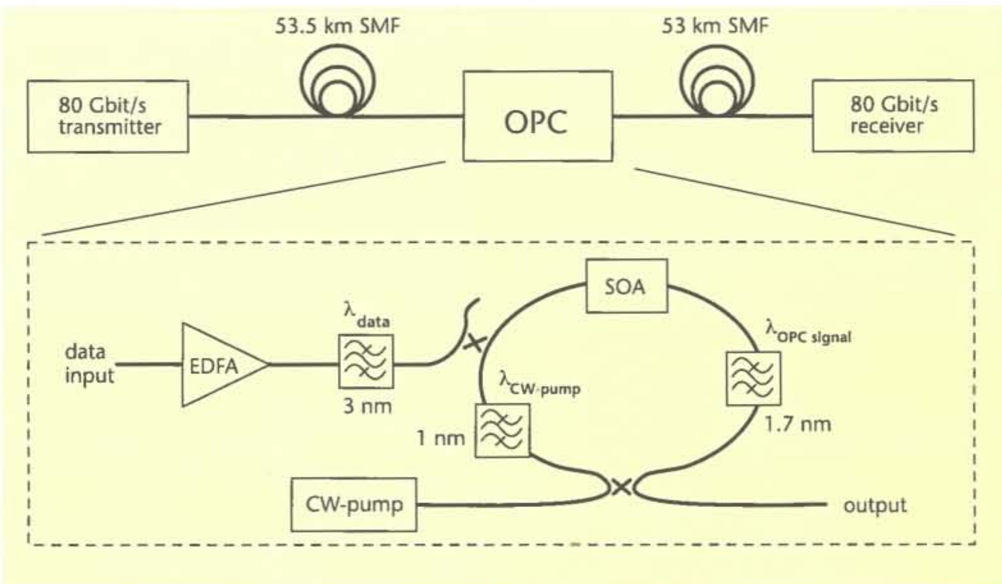
80 Gb/s Transmission over 106 km of Standard Fibre Using Optical Phase Conjugation in a Sagnac Interferometer

We report on 80 Gb/s transmission over 106 km of standard fibre (D = 16 ps/km/nm) using midspan spectral inversion (MSSI). The optical phase-conjugated signal is generated by four-wave mixing (FWM) in a semiconductor optical amplifier (SOA). The SOA is implemented in a Sagnac interferometer in order to achieve efficient continuous-wave pump suppression.

We recently described [1] an optical phase conjugator (OPC) for 80 Gb/s transmission based on FWM in an SOA, which was inserted in a Sagnac interferometer. The Sagnac interferometer served to suppress the strong pump wave. The experimental setup is shown in the figure. The 80 Gb/s data transmitter consisted of a 10 Gb/s transmitter driven by a 2^7-1 PRBS word, a fibre delay-line multiplexer (three stages) and a booster amplifier. The 80 Gb/s data signal (wavelength λ_{data} = 1551 nm, average power 8.5 dBm, pulsewidth full-width at half-maximum (FWHM) 1.2 ps, Fourier limited) was transmitted over 53.5 km of fibre. The dispersed signal was spectrally inverted in the OPC. The converted signal was then transmitted over a second fibre span of 53 km SMF. The 80 Gb/s receiver consisted of a SLALOM/TOAD-type all-optical demultiplexer and a 10 Gb/s receiver.

The suppression of the pump power when the generated phase-conjugated signal was filtered was a major problem, and was solved by the setup shown in the lower part of the figure. The CW pump (wavelength $\lambda_{CW\text{-}pump}$ = 1548.1 nm) was injected into the input of a Sagnac interferometer (loop mirror). By proper adjustment of the polarisation in the loop, the CW pump signal was strongly suppressed at the output.



Experimental setup for 80 Gb/s transmission over 106 km of standard fibre using MSSI

Error-free 80 Gb/s transmission over 106 km of standard fibre (D = 16 ps/km/nm) was demonstrated for the first time using midspan spectral inversion. The configuration used allowed very efficient suppression of the pump power without affecting the generated OPC signal. The accompanying simulations showed that the main limitation was due to second order dispersion, which was also the reason for the resulting penalty in the BER performance compared with back-to-back measurements. For larger transmission distances, additional techniques must be implemented to compensate for higher order dispersion.

This work is supported by T-Nova.

[1] U. Feiste, R. Ludwig, C. Schmidt, E. Dietrich, S. Diez, H.-J. Ehrke, E. Patzak, H.G. Weber and T. Merker, "80-Gb/s transmission over 106-km standard-fiber using optical phase conjugation in a Sagnac-interferometer", IEEE Photon. Technol. Lett., vol. 11, 1999, pp. 1063-1065.

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Gain-Transparent SOA Switch for High Bitrate OTDM Add/Drop Multiplexing

We report on a novel all-optical switch with high linearity, large switching contrast, low noise, wide bandwidth and low crosstalk. The switching principle, which is based on refractive index modulation in a wavelength band far from the gain region in a semiconductor-optical amplifier, was successfully demonstrated in a 640 Gbit/s demultiplexing experiment.

All-optical switches are key devices in future high capacity optical time division multiplexed (OTDM) systems. Recently, interferometric switches using semiconductor optical amplifiers (SOAs) have been widely investigated for demultiplexing and add/drop multiplexing applications. The optical control signal in these switches depletes the carriers in the SOAs in each interferometer branch with a relative time delay. The carrier depletion causes a change of gain and refractive index, and the phase change of the data signal is used for interferometric switching.

However, the gain change is unwanted, because it reduces the extinction ratio of the demultiplexer and causes amplitude modulation of the transmitted data. Additionally, there is a strong addition of amplified spontaneous emission (ASE) noise to the data signal, since the data signal is within the spectral region of the ASE.

These disadvantages are eliminated by the novel Gain-Transparent SOA switch (GT-SOA switch), which is schematically depicted in Fig. 1 in a Sagnac interferometer configuration (TOAD/SLALOM). The key element in the switch is a polarisation-insensitive 1.3 µm SOA. A data signal (wavelength 1.55 µm) and a control signal (1.3 µm) are coupled into the switch. The switch has outputs for the control signal, for the demultiplexed (dropped) data signal and for the transmitted data signal.

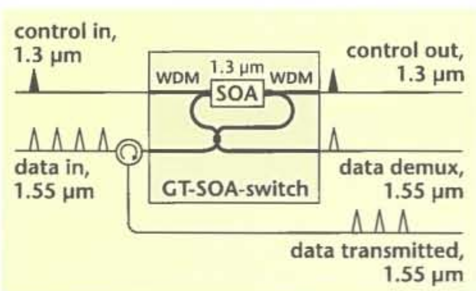

Fig. 1:
GT-SOA switch in a Sagnac interferometer (TOAD/SLALOM) configuration

Figure 2 shows a schematic spectrum of the ASE (or the gain) of the SOA, plus the spectra of the control and the data signals. In contrast to the case of a conventional nonlinear interferometric switch, the data signal is far from the maximum of the gain and ASE of the SOA. In fact, the SOA is virtually transparent to the data signal, since the photonic energy of the data pulses is significantly smaller than the bandgap energy of the semiconductor material. However, there is still a strong phase change in the data signal at 1.55 µm, which is induced by the control signal at 1.3 µm.

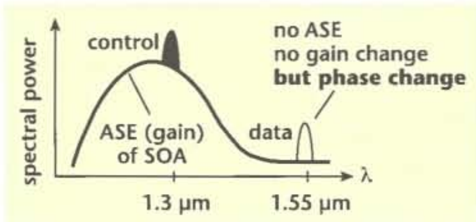

Fig. 2:
Schematic spectra of the ASE (or gain) of the SOA and of the control and data signals

In comparison with the conventional TOAD/SLALOM, the novel switch has high linearity (and therefore low crosstalk), low noise figure, large signal wavelength range, and no intensity modulation of the transmitted data signal.

The applicability of the novel switch for high bit rate system experiments was demonstrated in a 640 Gbit/s demultiplexing experiment [1]. Eight WDM channels, each carrying an 80 Gbit/s PRBS TDM data signal, were generated by four tunable modelocked semiconductor lasers using a spectral slicing technique. The multiplexed 640 Gbit/s data stream was transmitted over a short length (50 m) of fibre. The GT-SOA switch operated as a time division demultiplexer in the first stage of the receiver. Due to the high linearity and large wavelength range, the novel switch could demultiplex all 8 WDM channels simultaneously in the time domain (8x80 to 8x10 Gbit/s).

This work is supported by the German Ministry of Education, Science, Research and Technology under grant number 01 BP 436/1.

[1] S. Diez, R. Ludwig and H. G. Weber, "Gain-transparent SOA-switch for high-bitrate OTDM add/drop multiplexing", IEEE Photon. Technol. Lett. 11 (1), pp. 60-62, 1999.

Stefan Diez (Diez@hhi.de)

All-Optical Demultiplexer for 80 to 10 Gbit/s

Monolithically integrated Mach-Zehnder interferometers (MZIs) are essential for advanced all-optical signal processing functions for ultra-fast optical networks to be used by the coming information society. All-optical demultiplexing from 80 to 10 Gbit/s has been achieved using a push-pull driven symmetric MZI.

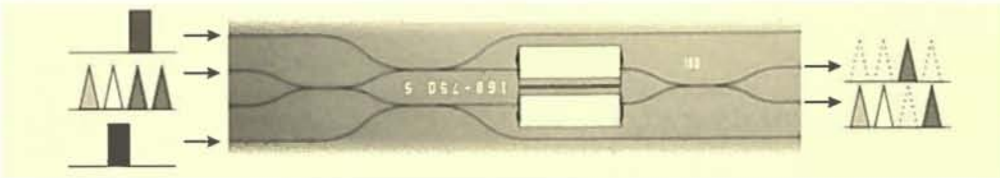

Fig. 1: The world's smallest all-optical demultilexer – a symmetric Mach-Zehnder interferometer with integrated semiconductor optical amplifiers as the nonlinear elements

Ultra-high speed OTDM systems with data transmission capacities up to the terabit region demand ultra-fast all-optical signal processing. All-optical demultiplexers have been one of the most investigated components for use in OTDM communication networks, and various approaches have been proposed and demonstrated [1].

In the Alcatel/HHI collaboration, the Mach-Zehnder interferometer structure (MZI) with semiconductor optical amplifiers (SOAs) as the active elements has been chosen due to its superior switching properties, compared to Sagnac and Michelson interferometers.

Two substructures have been investigated: the easy-to-handle asymmetric MZI with fixed switching windows determined by the longitudinal displacements of the SOAs, in which only contra-directional data and control pulses can be used, and the symmetric MZI with separate inputs for the control signals, in which both contra-directional and co-directional control is possible. The main advantage of the latter substructure is the ability to be used in a push-pull control scheme, in which both amplifiers are saturated separately with a controllable time delay, resulting in an adjustable switching window. As both amplifiers are in the same state on average, this scheme allows a much higher switching speed for demultiplexing and wavelength conversion applications than conventional schemes.

Monolithically integrated interferometers require various types of optical elements: high gain SOAs, compact low loss bends and couplers, efficient couplings with low reflections between active and passive sections, and low loss fibre couplings. These have been realised by using buried waveguides and buried heterostructure amplifiers with a butt coupling scheme at the active/passive interface. This compact solution leads to the world's smallest integrated demultiplexer device with the dimensions 4.5 x 1 mm^2 (Fig. 1).

System experiments have been performed successfully with both substructures: 40 to 10 Gbit/s demultiplexing using asymmetric MZIs, and up to 80 to 10 Gbit/s demultiplexing using co-directionally driven symmetric MZIs for any chosen arbitrary channels.

Modules of symmetric and asymmetric MZI devices have been realised in cooperation with the packaging group of the HHI, and have been used in system experiments at Alcatel.

The main future objectives are to reduce the optical losses further and to achieve demultiplexing from 160 to 40 Gbit/s. The monolithically integrated MZI will also play an important role as a basic building block in advanced all-optical signal processing functions such as decision, comparison, correlation, sampling, and signal conversion [2].

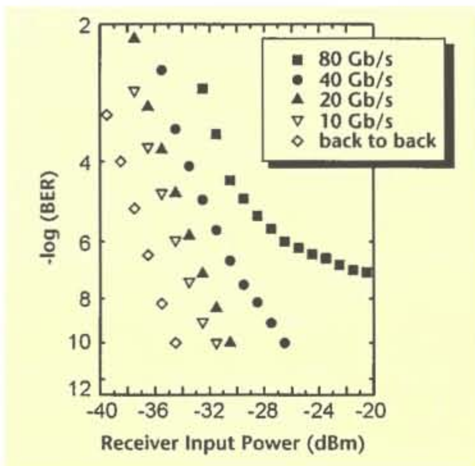

Fig. 2: Demultiplexing experiment – 10/20/40/80 Gb/s to 10 Gb/s

[1] T. Tekin and M. Schlak, "Update and comparison of existing solutions for OTDDmux", Report D-98/4, Alcatel-HHI collaboration "All optical signal processing", May 1999.

[2] B. Sartorius, M. Schlak, T. Tekin, A. Shen, J.G. Provost and F. Devaux, "Optical differentiator", Opto+/Alcatel CIT, patent application 99 10073 (France).

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High Power Picosecond Pulse Generation using Surface-Implanted InGaAsP/InP (λ = 1.53 µm) Laser Diodes

A cost-effective, on-wafer surface implantation technique was used for the fabrication of Q-switched InGaAsP/InP laser diodes. Picosecond pulses with large optical powers were obtained with a variety of design parameters.

Heavy ion implantation can produce a saturable absorber region and, when implemented in a laser resonator, enables the generation of short optical pulses in the picosecond region. However, the results published so far were obtained by implanting O, Ar, or N ions into the cleaved laser facets of single devices or arrays, which implies high fabrication costs and requires high implantation energy levels (e.g. N^{3+}, 25 MeV for c. 15 µm penetration depth).

By contrast, the work presented here was aimed at the on-wafer fabrication of short-pulse lasers using InGaAsP/InP with saturable absorbers created by masked heavy ion implantation.

In order to locally implant into the semiconductor material, a thick (3.5 µm) mask of electro-plated Au was applied, with openings at the absorber regions (Fig. 1). The advantages of surface implantation – radiation, rather, as the ions are implanted into the InP substrate – for the device design are evident, as now the absorber length and its position in the laser resonator can be varied at will. After implantation of N^{3+} ions (energy 7 MeV, dose $3{*}10^{11}$ ions/cm^2), the mask was removed and ridge-waveguide laser structures were fabricated.

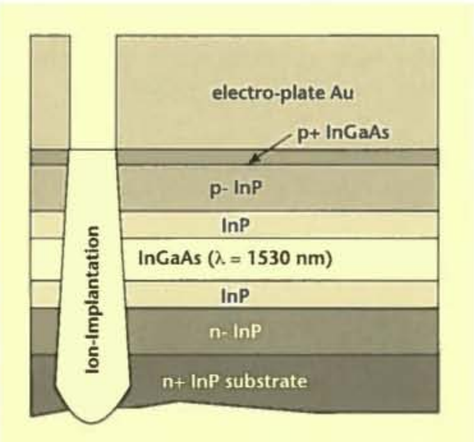

Fig. 1:
Schematic view of the InGaAsP/InP laser structure with the galvanised Au mask, which allows local N^{3+} implantation

In the Q-switching regime, the pulse power depends directly on the energy accumulated in the cavity just before absorber bleaching takes place. We have chosen in the present work to use bulk InGaAsP (λ = 1530-1540 nm) material instead of a quantum well (QW) structure for the active region, as this increases the volume and the quality of the saturable absorber. Stripe widths varied from 10-20 µm, and the typical resonator length was 300 µm.

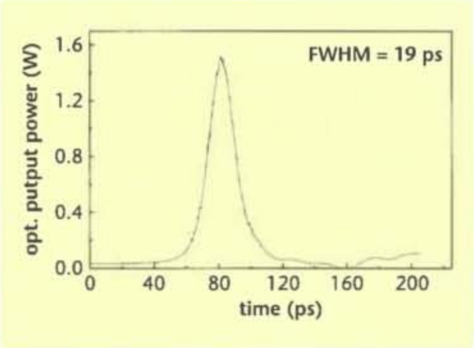

Fig. 2:
Typical short pulse characteristics of a surface-implanted Q-switched InGaAsP/InP laser driven by a 3 ns, 500 mA electrical pulse (stripe width 10 µm, absorber length 15 µm, resonator length 300 µm)

The lasers were pumped by 3 ns current pulses with a repetition rate of up to 100 kHz. Short-pulse generation was obtained with an impressive high yield. The devices were biased at I_{peak} = 400 – 500 mA. Under these conditions, solitary optical pulses with typical widths of 20 ps and peak powers exceeding 1 W (Fig. 2) could be demonstrated for a variety of stripe width/absorber length combinations.

In conclusion, a cost-effective surface-implantation technique has been developed for on-wafer fabrication of short-pulse InGaAsP/InP laser diodes. The achievement of 20 ps / 1 W peak power at high yield with these devices demonstrates a promising alternative to solid-state-lasers.

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Low Temperature MBE Growth for High Speed Materials

At the research level, fibre-based optical time division multiplex transmission (OTDM) continues to progress towards higher and higher bitrates. Even the achievement of 1 Tbit/s in the coming decade has been predicted. For this, ultra-high speed photonic devices with fs responses are required. The necessary improvement of the optical response of the base material can be achieved by reducing carrier lifetimes below those of conventional interband transitions. As one approach to this, the low temperature growth of GaInAs/AlInAs quantum-well materials was studied.

MBE growth of GaInAs/AlInAs at low growth temperatures (LT) leads to intrinsic defect formation and to incorporation of excess arsenic, as with GaAs. As a result, recombination lifetimes are substantially reduced due to ultra-fast capture of the excited carriers.

Aiming at the LT approach, the growth temperature dependence of the MBE deposition of GaInAs/AlInAs MQW absorber structures, which are key elements of future Tbit/s photonic components, was investigated. Single crystalline growth down to 100°C was successfully achieved, as demonstrated by the x-ray diffraction data in Fig. 1. Preservation of high optical quality is demonstrated by the appearance of PL emission from material grown even at 150° C. Additionally, distinct excitonic resonances are observed in the 300 K absorption spectra, even at reduced growth temperatures.

In general, the growth temperature dependence of the optical characteristics is determined by both well and barrier properties. The integrated PL intensity was found to be strongly reduced in the medium growth temperature range (350-450°C). This effect is obviously linked with the appearance of alloy clustering in the AlInAs barrier material [1], the quality of which markedly influences the QW recombination properties. Simultaneously, a reduction of lifetime by an order of magnitude occurs, down to some 100 ps, as shown in Fig. 2. Further reduction of the growth temperature towards the lower limit leads to a blue shift of the PL emission and a weakened excitonic oscillator strength in the absorption spectra. These effects are clearly related to the increase in the residual carrier concentration in the MQW structure. These carriers originate from the LT GaInAs [2]. This finding is in marked contrast to the behaviour with LT GaAs, but in agreement with that of LT InP. Thus, only a moderate reduction of lifetimes towards 50 ps appears. Further reduction towards the fs-region will be achieved by Be doping to compensate for the high residual carrier concentration originating in the LT GaInAs. A resulting decrease of lifetime to below 1 ps is expected.

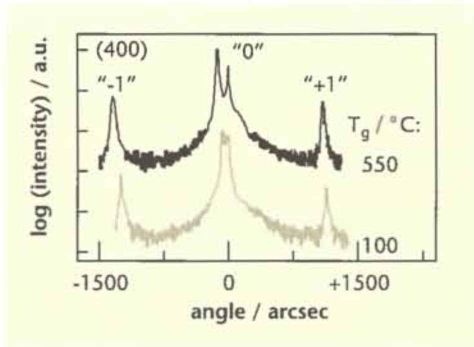

Fig. 1: X-ray diffraction of MBE AlInAs/GaInAs MQW grown at conventional and low temperatures

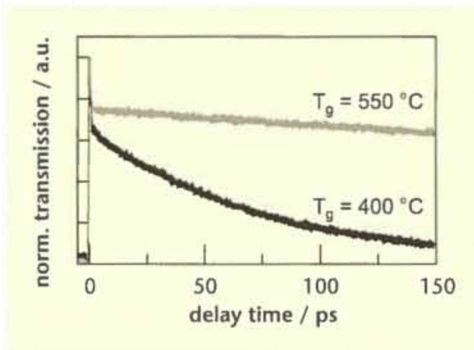

Fig. 2: MBE growth temperature dependence of MQW absorption recovery at 1.55 µm

[1] A. Hase, H. Künzel, D.R.T. Zahn and W. Richter, J. Appl. Phys. 76, 2459 (1994).

[2] H. Künzel, J. Böttcher, R. Gibis and G. Urmann, Appl. Phys. Lett. 61, 1347 (1992).

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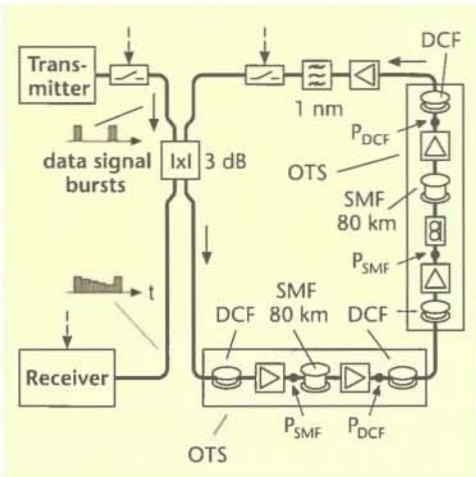
Simulation and Measurement of Dispersion-Managed Normalised Optical Transmission Sections for NRZ and RZ Formats

Normalised Optical Transmission Sections are means of simplifying network design and operation in future transparent optical WDM systems. Experimental and simulation results at 10 Gbit/s indicate that transparent links up to 4000 km are possible with cascaded 80 km sections.

Transparent optical WDM systems are increasing the capacity and flexibility of modern information networks. Future WDM networks are assumed to consist of transparent optical sections, in which a wide variety of data rates, data formats and wavelength channels is supported. The complex interaction of many physical effects limits the maximum transmission distances (transparency lengths). A strategy to simplify the network design and operation is to define so-called normalised Optical Transmission Sections (OTSs), which may be cascaded for longer links [1].



Examples of the simulation and measurement of a specific OTS (marked sections in Fig. 2) with 80 km of standard single mode fibre (SMF) and symmetrical compensation of the chromatic dispersion are shown. The simulation results (Fig. 1) indicate strong dependence of the transmission performance on the fibre input powers into the SMF and the dispersion compensating fibre (DCF) and on the degree of chromatic dispersion compensation (DoC). As an example, the inner dark area in Fig. 1 shows the tolerance range for 20 cascaded OTSs.

Measurements were performed in the loop testbed (Fig. 2) with NRZ and RZ formats. Fig. 3 shows the measured maximum transmission distances for different DoCs. The optimum was found to be at 99% DoC for NRZ and 100% for RZ, in good agreement with

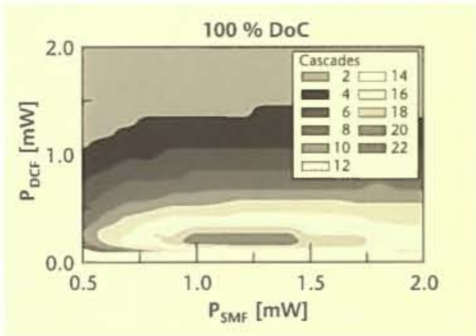


Fig. 2:
Loop testbed for the measurement of normalised Optical Transmission Sections (OTSs)

the simulation results. To achieve the largest transmission distances, the DoC has to be adjusted within 1%.

Other types of normalised OTSs with pre- and post-compensation are still under investigation.

Fig. 1:
Example of a simulated tolerance map for OTS power levels with 100% chromatic dispersion compensation (DoC) and NRZ signals (source: N. Hanik)

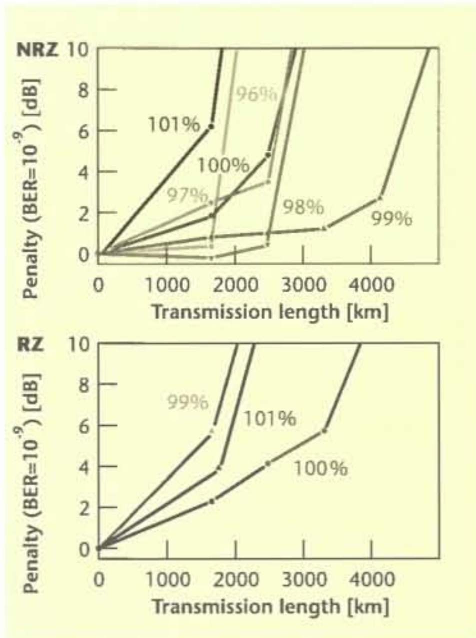


Fig. 3:
Measured BER penalty as a function of the transmission length for NRZ and RZ formats at optimised fibre input powers, with percentage of DoC as parameter

This work is supported by the T-Nova Deutsche Telekom Innovationsgesellschaft mbH under the framework of the German KomNet programme.

[1] N. Hanik, A. Gladisch, H.-M. Foisel, C. Caspar, U. Hilbk, F. Schmidt and E. Schulze, „NRZ/RZ data format transparency of dispersion managed fibre links", Proc. ECOC '99, Nice, Sept. 99, Vol. I, pp. 40-41.

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3R Signal Regeneration in a Loop Experiment at 10 Gb/s

An all-optical 3R signal regenerator has been developed which uses a self-pulsating DFB laser for clock recovery and a Mach-Zehnder interferometer with integrated SOAs for the decisions. The performance of the regenerator is evaluated by loop experiments, in which 300 sections of DSF, each of 50 km length, are effectively cascaded, giving a transmission distance of 15,000 km. The BER performance is constant after the first section, which demonstrates that the optical regenerator suppresses the accumulation of noise and jitter.

All-optical 3R signal regeneration (Re-amplification, Re-timing, Re-shaping) is a key function needed for scalable all-optical networks. Main functional blocks are the optical clock recovery and the decision element.

A self-pulsating DFB laser developed at the HHI is applied for clock recovery. In preliminary tests it was verified that the clock jitter was sufficiently low [1] and that the clock pulses had an optical quality that met the transmission requirements. The device used for decision, which was developed by Alcatel, is an all-active Mach-Zehnder Interferometer (MZI) with integrated SOAs. It is operated as a nonlinear gate that either blocks or transmits the clock pulses. The gate is controlled by the data signal, whereby the nonlinear sinusoidal transfer function of the interferometer suppresses the effect of noise in the data signal. The operating conditions of the MZI [2] are chosen in such a way that the switching window of the gate is wider than the duration of the clock pulses. Hence jitter in the data pulses or gate position is not transferred to the clock pulses. The overall result is that the data information is encoded onto the clock pulses without noise or jitter.

The performance of the regenerator was evaluated at 10 Gb/s RZ in a loop testbed at Alcatel (Fig. 1). The loop contains 50 km of dispersion-shifted fibre (DSF), the regenerator, and several fibre amplifiers (not shown). An additional wavelength conversion provides the regenerator with an internal wavelength.

The data signal (PRBS with word length 2^7-1) is launched into the loop and the reception sensitivity (i.e. the power required for a BER of 10^{-9}) is measured after each lap. The results are shown in Fig. 2. The first transmission through the regenerator has a penalty of 1 dB compared with an injected signal of best quality. However, there is no additional penalty in the subsequent laps, and the quality of the optical data signal stays constant. This demonstrates that the regenerator suppresses the accumulation of noise and jitter. 300 laps were traversed in this experiment, which represents a transmission length of 15,000 km.

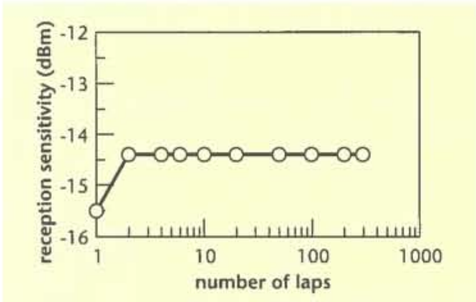

Fig. 2: Performance of regenerator: The constant reception sensitivity after the first lap indicates that the accumulation of jitter and noise is suppressed

The speed potential of the regenerator is higher than the demonstrated 10 Gb/s. Operation at 40 Gb/s has already been demonstrated for both self-pulsating lasers and MZIs, and a 40 Gb/s regenerator is presently being assembled.

[1] B. Sartorius et al., "All-optical clock recovery module based on a self-pulsating DFB laser", Electron. Lett., 34, pp. 1664-1665, 1998.

[2] B. Lavigne et al., "Test at 10 Gbit/s of an optical 3R regenerator using an integrated all-optical clock", ECOC '99, Nice, France, Proc. II, pp. 262-263, 1999.

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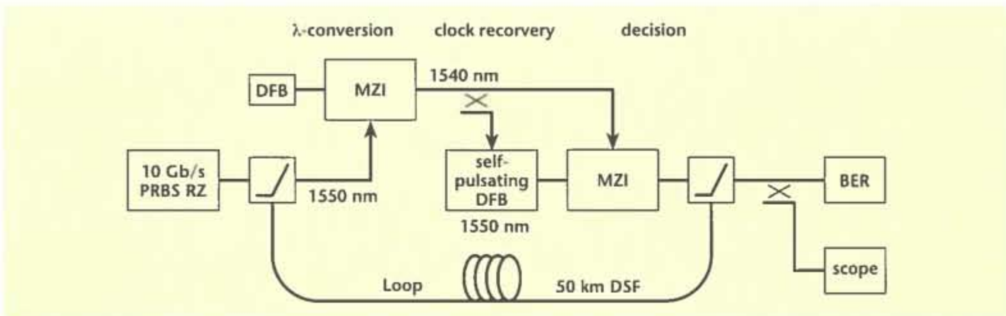

Fig. 1: Schematic diagram of regenerator and testbed

Modelling of All-Optical Sub-Systems for Photonic Networks: 3R Regenerator

All-optical signal processing functions, such as 3R regeneration, packet routing and demultiplexing, are needed for high-speed photonic networks. Modelling activities for the analysis, evaluation, optimisation and design of photonic devices, circuits and networks are performed in parallel with our experimental work. Recent results on a 3R regenerator circuit are presented.

Optimal utilisation of the self-pulsation effect of semiconductor multi-section lasers for clock extraction in a 3R regenerator can only be obtained with a fundamental understanding of the underlying laser dynamics. Two simulations – one based on a Finite Difference (FD) solution of the combined rate and wave propagation equations in the time domain, the other on a transmission line laser model (OPALS, which is commercially available) – show good agreement in large islands of self-pulsation for optimised devices. High frequency operation up to 40 Gbit/s is predicted.

Using the transmission line laser model, it is possible to combine several devices to form complex all-optical circuits. A complete 3R regenerator circuit is investigated here. It is composed of a self-pulsating laser for the clock recovery and a nonlinear Mach-Zehnder interferometer with SOAs, which is used as an optical gate. The MZI is operated in a push-pull configuration to increase the speed. This scheme is shown in Fig. 1. The first step in the modelling is to optimise the parameters of each component. Next the clock has to be locked to the incoming data signals, which is checked using eye diagrams. The (virtual) sampling scope is triggered by the data signal and the clock pulses are displayed as shown in Fig. 2. A pulse trace is visible only when locked. The width of the trace is a measure of the clock jitter.

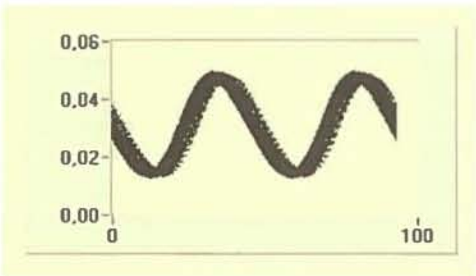

Fig. 2:
Eye diagram of a 20 GHz clock locked to a 20 Gb/s data stream

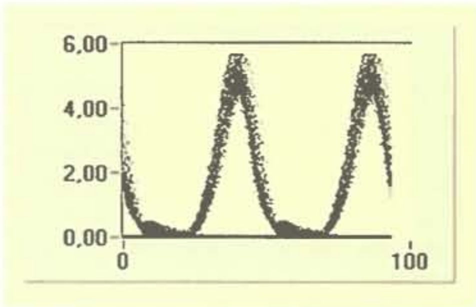

Fig. 3:
Eye diagram of the output signal from a complete 3R regenerator operating at 20 Gb/s

Finally, the amplitudes and relative phases of the data and clock output signals are adjusted. Operation of the complete circuit is demonstrated by analysing the eye diagram of the output signal from the MZI gate, which is shown in Fig. 3. The simulations show that this configuration can operate up to 40 Gbit/s.

In future work we will investigate 3R regeneration in a fibre loop, with special emphasis on the influence of jitter accumulation.

[1] M. Radziunas et al., "Modeling of new grating designs for self-pulsating DFB lasers", Technical Digest, IPR, 1999, St. Barbara, Ca, USA, July 19-21, 1999, paper RWC3, pp. 358-360.

[2] H.-P. Nolting, "Modeling of all optical functional devices for signal processing: 3R-Regeneration", ibid., paper RWC2, pp. 355-357.

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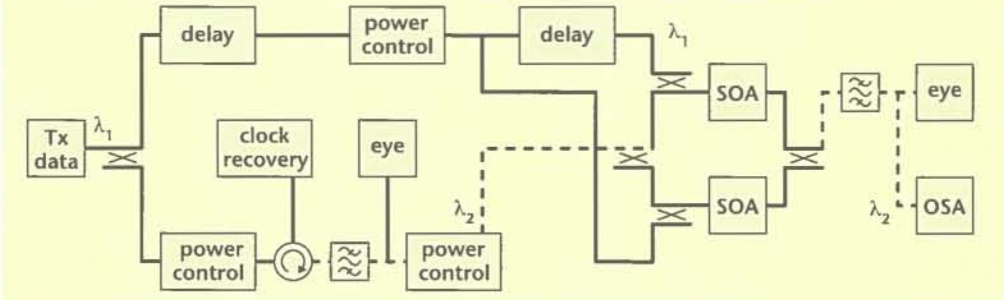

Fig. 1:
The architecture of a 3R regenerator with a clock recovery system and a Mach-Zehnder interferometer using semiconductor optical amplifiers (SOA) in a push-pull configuration

Design of Ultrahigh Bitrate TDM/WDM Transmission Systems

Starting from the successful numerical simulation of a 4x40 Gbit/s transmission experiment over 100 km of single mode fibre (SMF), we numerically evaluate the feasibility, including the required tolerances, of transmitting eight channels at 40, 80 and 160 Gbit/s per channel over 500 km of SMF.

Recently four WDM channels, each carrying data at 40 Gbit/s, were transmitted over a 100 km single mode fibre (SMF) link in RZ format [1]. The fibre link consisted of a 100 km SMF span with an EDFA (Erbium-doped fiber amplifier) and a dispersion compensating fibre (DCF). The experiment was also simulated numerically, and the calculated results were in good agreement with the experiment.

A DCF (labelled DCF1) is used in the 4x40 Gbit/s experiment to fully compensate the second order dispersion D, but not the third order dispersion S. The results of the calculations, shown in Fig. 1, indicate that at most three spans can be cascaded with such compensation. If, however, DCF2 is used, which compensates both D and S, the penalty curve has the same shape but is 3 dB lower. A similar curve is also obtained if the dispersion is compensated at the receiver, e.g. by a fibre Bragg grating.

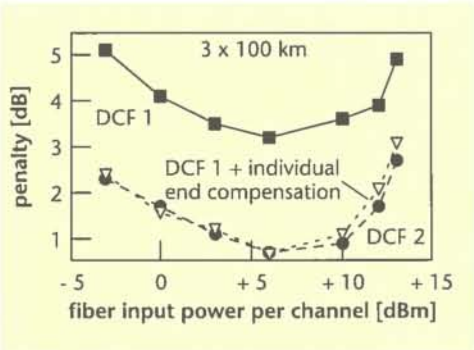

Fig. 1: **Eye closure penalty for 4x40 Gbit/s transmission over a 300 km SMF**

Next we numerically investigated the cases of 8x40, 8x80 and 8x160 Gbit/s transmission over 5x100 km of SMF with 100 km amplifier spacings. In order to compare the results with the 4x40 Gbit/s experiment, pulse widths of 4, 2 and 1 ps and channel spacings of 2, 4 and 8 nm were taken for the 40, 80 and 160 Gbit/s systems, respectively. Each span was assumed to be completely compensated by DCF2. An important conclusion from the calculations is that four-wave mixing and cross-phase modulation effects are negligible with the dispersion map and channel spacings considered.

We then varied the SMF length from the value required for complete compensation in order to evaluate the stability of transmission with respect to small changes in the degree of dispersion compensation. The variations with SMF length are due to increased broadening of the pulses caused by deviations of the total dispersion from zero. The optimum input power is 10 dBm per channel. In Fig. 2 we show the calculated eye closure penalty for deviations from the ideal fibre length. In order to keep the transmission penalty below 3 dB, SMF length tolerance ranges of 1.1, 0.28 and 0.07 km are required for the 4, 2 and 1 ps pulse widths, respectively. Since length tolerances much less than 1 km are difficult to realise, a way must be found to increase the above numbers. Since, for non-soliton transmission, pulse broadening due to dispersion depends inversely on the square of the pulse width, the above length tolerances are increased by a factor of four if pulse widths of 8, 4 and 2 ps are used for transmission at 40, 80 and 160 Gbit/s, respectively.

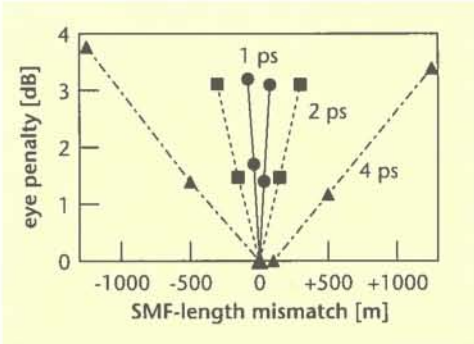

Fig. 2: **SMF length tolerances for RZ transmission over 500 km of SMF with 4, 2 and 1 ps pulse widths**

This work is supported by the German Ministry of Education, Science, Research and Technology (BMBF) under grant no. 01 BP 903 (KomNet).

[1] W. Pieper, R. Ludwig, C.M. Weinert, B. Kuhlow, G. Przyrembel, M. Ferstl, E. Pawlowski and H.G. Weber, "4-channel x 40 Gb/s unrepeatered OTDM transmission over 100 km standard fiber", IEEE Photon. Technol. Lett, vol. 10, pp. 451-453, 1998.

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40 Gb/s Photoreceivers on InP with Flattened O/E Transfer Characteristics

Photoreceivers are key components in high bit rate telecommunication systems. This report describes on-going improvements, especially in terms of receiver bandwidth and group delay scatter, in the InP-based monolithic integration of a front end with a waveguide-integrated photodiode (WG-int. PD) and a travelling wave amplifier (TWA).

The transport capacity of worldwide telecommunication networks is steadily increasing, driven by the rapidly growing Internet, in which data traffic more than doubles each year [1]. Optical long-haul systems are consequently being upgraded to 40 Gb/s data rates with WDM multiplexing. The corresponding photoreceivers should have about 40 GHz bandwidth and good phase linearity.

The photoreceiver OEICs were designed for flat response (better than ±1 dB) and for a group delay scatter within ±15% of the 40 Gb/s bit period [2]. The TWA concept was chosen because of its potential for future bandwidth expansion and its good exploitation of the HEMT cut-off frequency in relation to the overall amplifier bandwidth (i.e. amplifier bandwidth/ $f_{T,HEMT}$ > 50%). The design of the monolithically integrated amplifiers in the WG-int. PD and TWA was further improved, as compared to last year's design, by optimising the impedances of selected transmission lines in the TWA in relation to the properties of the quarter micron gate HEMT (e.g. f_T/f_{max} values of 80/200 GHz).

Fig. 1: View of the pinTWA photoreceiver OEIC, showing the monolithic integration of a waveguide-fed photodiode and a distributed amplifier composed of four e-beam gate HEMTs

The photoreceiver OEICs were fabricated using a two-step MOVPE/MBE epitaxial approach for the WG-int. PD/HEMT layer stacks, which allows independent optimisation of the individual devices. The photodiode and HEMT areas are defined by wet chemical mesa etching. Fig. 1 shows the complete receiver OEIC with four HEMTs in the distributed amplifier. The mushroom-shaped gates of the HEMTs were fabricated by e-beam gate lithography using a three-layer resist.

The subsequent MMIC processing includes the formation of the NiCr resistors, MIM capacitors, and metallisation for the conductors and air bridges.

The TWAs of the photoreceiver OEICs were characterised on-wafer with a network analyser over the frequency range 45 MHz to 50 GHz. A group delay scatter within ±5 and ±7 ps was achieved over frequency ranges of 30 and 45 GHz, respectively.

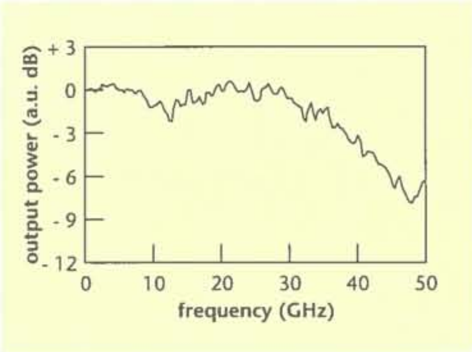

Fig. 2. Optoelectronic power transfer function of the photoreceiver OEIC

Figure 2 shows the optoelectronic power transfer function of the photoreceiver OEIC, obtained by optical heterodyne measurements at 1.55 µm wavelength. The 3 dB bandwidth is almost 40 GHz and the transfer function ripple is less than ±1 dB.

Several photoreceiver OEICs were packaged and supplied to industry partners in the KomNet programme for system characterisation.

This work is supported by industrial partners within the KomNet programme.

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Dynamic Range of Monolithic Optic/Millimetre-Wave Converters

The dynamic range of monolithic InP-based photoreceivers for narrow band optic/millimetre wave conversion is investigated. Detailed circuit simulations using a library of equivalent circuits show excellent agreement with characterisations obtained using heterodyne measurements at $\lambda = 1.55$ µm.

Fibre-fed cellular networks operating in the millimetre wave range will be the backbone of future mobile access broadband services, offering data rates of up to 155 Mbit/s per subscriber. A key component in the base stations of such systems is the optic/millimetre-wave converter. For this purpose we have designed and successfully fabricated InP-based opto-electronic integrated circuits (OEICs). These comprise a metal-semiconductor-metal photodetector (MSM PD) and a three-stage narrowband amplifier using high electron mobility transistors (HEMTs), and work in the 38 and 60 GHz regimes [1], [2]. The dynamic range of these OEICs is limited by noise at low optical input powers and by nonlinearities at high power levels. Both effects, which are caused by the MSM PD as well as the HEMTs, were investigated using circuit simulations for the 38 and 60 GHz OEICs. The simulations of the 38 GHz OEIC were confirmed by heterodyne measurements. A set of verified small-signal, large-signal and noise models for the MSM PD and HEMT were used in the simulations [2].

As can be seen from Fig. 1, noise increases with optical input power. This is due to shot noise induced by the photo drift currents in the MSM PD, while the noise floor at low optical input powers is mainly caused by noise generated in the first HEMT stage of the amplifier.

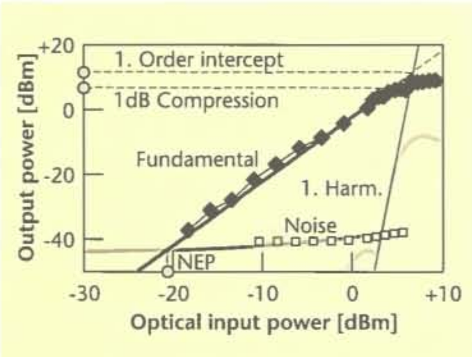

Fig. 1: Measured and simulated millimetre wave output power and noise as functions of the optical input power (38 GHz OEIC)

By integration of the noise power density (see Fig. 2), the noise equivalent power (NEP) of the 38 GHz OEIC is found to be -20.5 dBm.

Regarding nonlinear effects, measurements of the electrical output signal of a discrete MSM PD showed linear behaviour up to an optical input power of +8 dBm. Clearly, up to this level the accumulation of space charges under the electrodes of the MSM PD does not cause any compression of the output power. As confirmed by the circuit simulations, the 1 dB compression point of the 38 GHz OEIC at +6 dBm (see Fig. 1) is caused by compression in the HEMT of the last amplifier stage.

Simulations of the 60 GHz OEIC show a NEP of -15 dBm and more than 0 dBm maximum output power, which is limited by the power capability of the MSM PD.

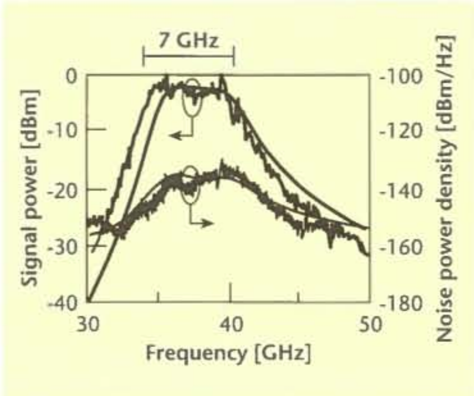

Fig. 2: Measured and simulated millimetre wave output power and noise as functions of frequency for the 38 GHz OEIC

[1] Th. Engel, A. Strittmatter, W. Passenberg, E. Dröge, A. Umbach, W. Schlaak, R. Steingrüber, A. Seeger, G.G. Mekonnen, G. Unterbörsch, H.-G. Bach, E H. Böttcher and D. Bimberg, "38 GHz narrow band photoreceiver OEIC with MSM photodetector and HEMT amplifier", Proc. 24th ECOC '98, Madrid, Spain, Sept. 20-24, 1998, pp. 63-64.

[2] Th. Engel, G. Unterbörsch, R. Hübsch, G.G. Mekonnen and D. Bimberg, "Noise and nonlinearity of monolithic 38 GHz photoreceiver for optic/millimeter-wave conversion", Proc. 25th ECOC, Nice, France, Sep. 26-30, 1999, vol. 2, pp. 158-159.

Thomas Engel (Thomas_Engel@hhi.de)

Ultrafast High-Power Twin Photodiodes for 40 Gbit/s Systems

A photoreceiver PIC based on InP was designed for a 40 Gbit/s TDM system. It consists of a MMI coupler and balanced twin photodiodes. The output signal from the receiver can be fed directly into the differential input port of the following demultiplexer IC. The photodiodes have a responsivity of about 0.5 A/W, a bandwidth of more than 50 GHz, and excellent high-power behaviour. The responses of the two photodiodes are very similar, mainly because of the monolithic integration of the electrical circuitry, enabling the desired differential control of the demultiplexer.

The receiver front end in a 40 Gbit/s TDM field trial being carried out by a partner from industry uses an EDFA as preamplifier to obtain reduced noise, compared to electrical post-amplification, as well as power level control in the optical domain. As a new concept, the incoming optical signal is split in the photoreceiver and then converted to electrical signals by a pair of photodetectors. The resulting output signal can be fed directly into the differential input port of the following digital demultiplexer IC. This photonic integrated circuit (PIC), which is based on InP, consists of a spot-size transformer at the optical input, an optical 3 dB power splitter, two balanced pin photodiodes, and biasing circuitry (Fig. 1).

A multi-mode interference (MMI) coupler structure acts as a power splitter. The pin photodiodes are located on top of the optical waveguides to utilise evanescent field coupling. Because of the distributed light absorption, the photodiodes can handle very high optical pulse energies. Pulse measurements in the time domain using a fast optical source, which produced picosecond pulses with high power levels, confirmed this behaviour up to outputs of more than 500 mV, which is sufficient to directly drive the demultiplexer stage. The electrical RF circuit and biasing network is designed to produce a symmetric RF signal in the double line coplanar stripe output port.

Due to the integrated spot-size transformer, the responsivity is about 0.5 A/W, and relaxed adjustment tolerances greater than 1 µm (for 1 dB additional loss) for fibre-chip coupling are achieved. The small active size of the photodiode (5x25 μm^2) gives a bandwidth of more than 50 GHz.

The most critical design aspect is the equality and uniformity of the photodiode responses in the frequency domain, since any asymmetry leads to signal distortion in the following demultiplexer stage. Figure 2 shows the frequency behaviour of the separately measured photodiodes using an on-wafer heterodyne technique. The flat responses and small variations (less than 2 dB in the important frequency range) between the diodes is sufficient for balanced operation up to 40 Gbit/s.

Receiver chips were mounted in laboratory-type housings and 40 Gbit/s eye pattern measurements were made by the industry partner, with only one photodiode of the receiver connected to the RF path. The clearly opened eye (Fig. 3) again demonstrates excellent suitability for 40 Gbit/s systems.

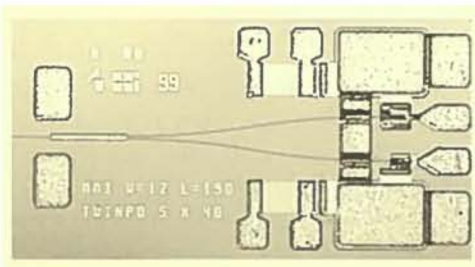

Fig. 1:
Microscopic view of the photoreceiver

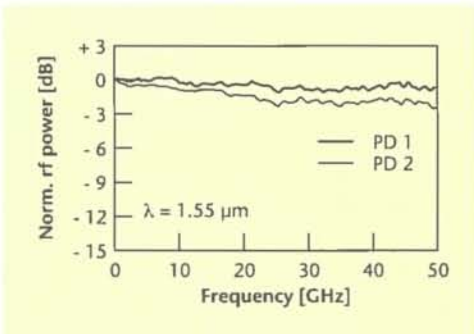

Fig. 2:
Frequency behaviour of the photodiodes PD1 and PD2 in the receiver

This work is supported by the German Ministry of Education, Science, Research and Technology (BMBF) under grant number 01 BP 811.

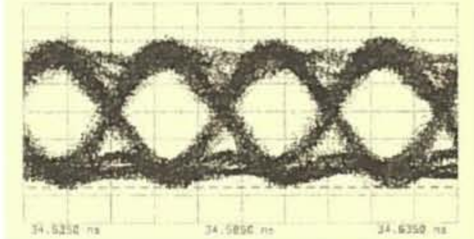

Fig. 3:
40 Gbit/s eye diagram of a module in which only one photodiode is connected (10 ps/div, 40 mV/div)

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Reusable Multipurpose Packaging of OEICs for Bandwidths up to 50 GHz

We developed a series of modules for fibre-chip coupling of InP-based OEICs. Simultaneous coupling of both chip sides to fibres is possible with the new patented set-up. Typical coupling losses are 3-5 dB. The modules withstand temperature cycles between –20°C and +70°C and mechanical stresses up to 16 g (vibrational) and 200 g (shock).

Fast transmitter and receiver modules are basic elements of future high bandwidth optical communication systems. We designed and fabricated a series of modules for fibre-chip coupling of InP-based optoelectronic integrated circuits (OEICs) that are well suited for laboratory test beds and field trials.

A fibre-chip coupling unit [1] has been developed for double-sided coupling of waveguide-fed OEICs (Fig. 1). The OEIC is placed in the centre of a miniature optical bench. A Peltier cooler controls the temperature of the bench. The optical fibre is fed into a metal tube and fixed by glue, solder or laser welding. One end of the tube is clamped at one end of the bench while the other is then precisely moved in the x and y directions by two adjusting pins driven by piezo manipulators. The z direction is adjusted by longitudinal shifting of the metal tube. After optimal adjustment of the tapered fibre with respect to the OEIC facet, the adjusting pins are fixed by a screw, glue, or laser welding. A manipulator tool was specially designed for easy adjustment of all axes of the fibre. Typical coupling losses from 3 to 5 dB are obtained.

The module consists of the miniature optical bench, which contains the OEIC, the tapered fibre, and the adjusting pins. The bench is located on top of two Peltier coolers for thermal stabilisation of the OEIC. The RF is fed via two semirigid cables from the V-type connectors directly to the OEIC without a glass bead [2]. This guarantees good high frequency response. One type of module is especially designed for double-sided access, as needed for instance for semiconductor amplifiers, while another variant is for single-sided coupling, as shown in Fig. 1.

We performed long-term temperature tests with several modules between +15°C and +40°C and between -20°C and +70°C. The maximum variation of the coupling efficiency was ±0.15 dB. We completed the testing with mechanical shock and vibrational stress tests. The shock acceleration was more than 200 g and the vibrational acceleration more than 16 g, but no significant degradation of the coupling efficiency was observed.

To characterise the RF properties of the module we short-circuited the two semirigid cables leading from the two V-connectors to the OEIC port, and measured the electrical reflection S_{11} and the transmission S_{21} with a HP network analyser. The reflections are as low as -30 dB at 1 GHz and -12 dB at 50 GHz, which shows nearly perfect electrical adaptation of the V-connectors with the RF line. The loss was mainly that of the cable (50 dB/m) back to the output connector. If there is no need for the back line there will be only 3 dB cable loss from the input V-connector to the clip.

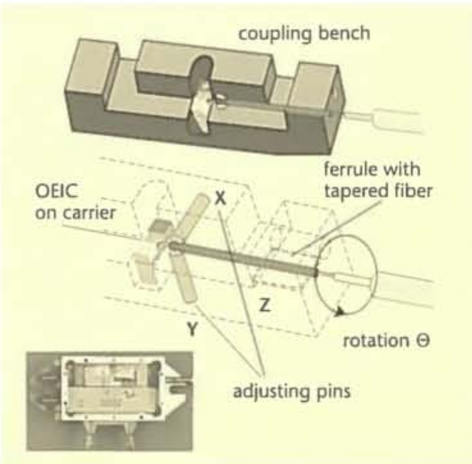

Fig. 1: Patented coupling scheme

The S_{21} characteristics have very smooth behaviour. At 50 GHz there is a loss of less than 6 dB for the whole cable loop length of 100 mm from input to the OEIC end.

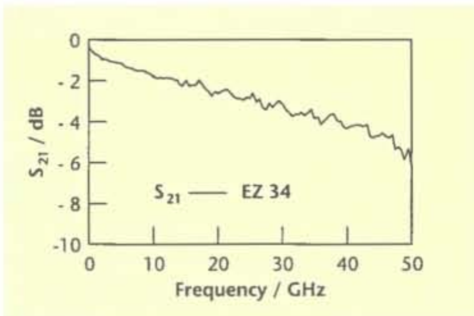

Fig. 2: Transmission loss S_{21} of an OEIC connection

[1] K. Peters, HHI, Patents DE 195 36 185.7 and DE 195 36 173.3.

[2] D. Rohde, et al., "Optic/millimeter-wave converter for 60 GHz radio-over-fiber systems", MIOP '97, Conf. Proc., pp. 311-315.

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A Novel Technique for the Fabrication of Optical Spot Size Converters for InP-Based PICs

A new technology for the fabrication of optical spot size converters is presented. Using only quasi-standard process equipment, spot size converters with virtually any ramp shape can be fabricated with very good reproducibility and excellent uniformity. The integration of waveguide-fed photodetectors with these converters gives doubled responsivity and one order of magnitude larger alignment tolerances, compared to photodetectors without spot size converters.

Spot size converters (SSCs) are key elements of photonic integrated circuits (PICs), since they significantly reduce the effort and cost of the device packaging as well as the fibre-to-chip coupling losses. The basic technological challenge is the fabrication of a vertical ramp with a maximum height of around 1 µm and a length of 500-1000 µm. Our new technical approach is shown schematically in the figure. The idea is first to create lithographically an image of the desired ramp in photoresist. This resist ramp is produced by shifting a mask with a window during the exposure cycle. In the next step the resist ramp is transferred to the waveguide layer by ion beam etching (IBE). During this process both the resist mask and the semiconductor are etched simultaneously. The final profile of the tapered ramp is determined by the etch rate selectivity.

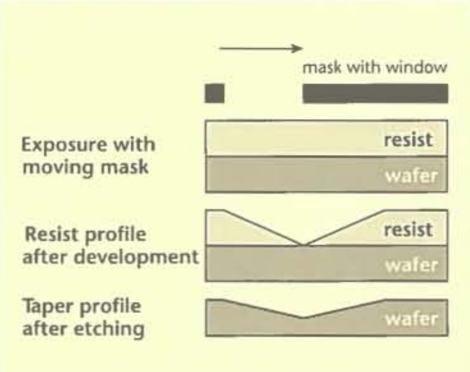

Fig.:
Processing steps for the fabrication of spot size converters

A special low contrast resist (Micro Resist Technology ma/P3.OG) and a standard contact printer were employed for all experiments. The mask aligner has modified software that allows the precise movement of the mask relative to the wafer during the exposure cycle in proximity mode. To fabricate arbitrary resist profiles, up to ten moves with different velocities and lengths can be used. If the contrast curve of the resist is known, the profile can be calculated by integrating the movement equation of the mask. Calculations of different resist profiles were performed and compared with fabricated resist profiles. In all cases the predicted and actual resist profiles were almost identical.

The transfer of the resist profile to the semiconductor waveguide is performed by IBE with an N_2/O_2 gas mixture. The transfer ratio, i.e. the ratio of the etching rates of the resist and the semiconductor, can be controlled by choice of the O_2 content in the etching gas. Experimental results show a reproducible and almost linear dependence of the transfer ratio on the oxygen flow.

Waveguides with SSCs at both ends were fabricated. The variation of the insertion loss over a two inch wafer was only ±0.1 dB, which shows the excellent uniformity of the new technique.

Waveguide-fed photodetectors with integrated SSCs using an optimised layer design were fabricated. The main results are summarised and compared with those of similar photodetectors without SSCs in the table. The results demonstrate that the integration of SSCs fabricated by the new technique doubles the responsivity, while the alignment tolerances are about an order of magnitude larger.

Photodetector	With SSC	Without SSC
Fibre	Cleaved	Lensed
Responsivity (A/W)	0.7	0.3
1 dB vertical alignment tolerance (µm)	± 2.5	± 0.25
1 dB horizontal alignment tolerance (µm)	± 3.5	± 0.5

Table:
Responsivity and alignment tolerances of waveguide-fed photodetectors with and without integrated spot size converters

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Interface Conduction in Semi-Insulating MOVPE Layer Stacks

MOVPE-grown Fe-doped semi-insulating GaInAsP/InP optical waveguide layer stacks, which are used in the optoelectronic integration of high-speed photoreceivers, are characterised by admittance spectroscopy. A new procedure, based on circular current distribution analyses over a range of frequencies, is presented for estimating both the residual buried interface sheet conductivity and the bulk properties of the layer stack.

Optoelectronic integration, e.g. with waveguide-integrated photodiodes and active electronic devices such as HEMTs, uses a buried semi-insulating optical waveguide layer stack [1]. This stack must electrically insulate all integrated devices from each other. A common specification for this buried layer stack is to have an average specific resistance ρ comparable to that of the semi-insulating substrate, i.e. $\rho > 10^7$ Ωcm. However, for proper a.c. isolation of the devices, i.e. to avoid capacitively induced crosstalk effects, a minimum sheet resistance greater than 10^6 Ω/sq is also needed. This work reports on an effective procedure for estimating any residual buried interface conductivity inside semi-insulating layer stacks as well as for determining the resistive properties of the waveguide stack and the substrate.

The semi-insulating optical waveguide layer sequence is grown by MOVPE. The layer details of a typical structure are given in [2]. Semi-insulating properties are obtained by Fe doping of all waveguide layers ($3\text{-}6 \cdot 10^{16}$ cm^{-3}).

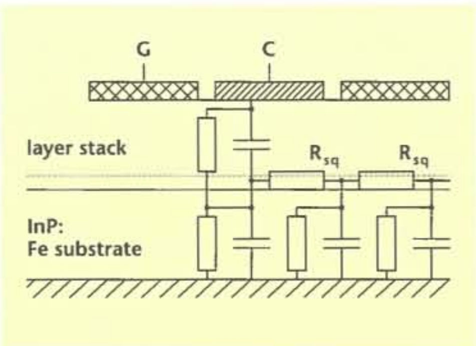

Fig. 1: **Test setup and equivalent circuit for substrate and layer stack, showing capacitive and conductive elements and the interface sheet resistance R_{sq}**

Figure 1 shows the test structure for the electrical characterisation, together with the equivalent circuit of the semi-insulating layer stack on top of the InP:Fe-doped substrate. If the breakdown voltage between the centre C and the guard ring contact G, separated by a typical distance of 8-10 µm, exceeds values of 30-40 V, sufficient bulk insulation of the layers is confirmed. However, an additional measurement of capacitance and conductance over a broader frequency range (100 Hz to 10 MHz) is necessary to ensure a.c. isolation.

The frequency-dependent admittance, e.g. as in Fig. 2, can be interpreted quantitatively to estimate the bulk conductivity of the layers as well as the excess interface sheet resistance.

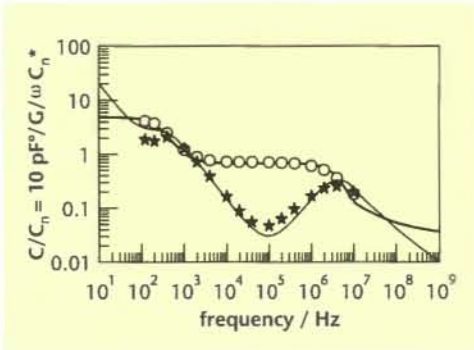

Fig. 2: **Admittance of a sample with non-vanishing interface sheet conductance (normalised measured capacitance ∘ and a.c. conductance *; the full lines are calculations based on Fig. 1)**

If it appears at all, the plateau of capacitance between 10^4 and 10^6 Hz depends on the depth of a conducting interface between substrate and buffer layer. From comparisons between measurements and calculations, a sheet resistance of 25 kΩ/sq is derived in this case. Our investigations revealed that this conducting interface is avoided by improved cleaning procedures prior to MOVPE growth.

[1] A. Umbach, T. Engel, H.-G. Bach, S. v. Waasen, E. Dröge, A. Strittmatter, W. Ebert, W. Passenberg, R. Steingrüber, W. Schlaak, G. G. Mekonnen, G. Unterbörsch and D. Bimberg, "Technology of InP-based 1.55 µm ultrafast OEMMICs: 40 Gbit/s broadband and 38/60 GHz narrow-band photoreceivers", IEEE J. of Quantum Electronics, Vol. 35, No. 7, 1999, pp. 1024-1031.

[2] H.-G. Bach, W. Ebert, A. Umbach, C. Schramm, R. Hübsch and A. Seeger, "Optimizing Fe-doped semi-insulating optical waveguide layers: Detection of interface layer conduction", 26th International Symposium on Compound Semiconductors (ISCS '99), Conference abstracts: Paper MoP.1, 22-26 August 1999, Berlin.

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Development of Bi-Directional Full-Duplex 1.3 μm/1.5 μm Transceiver ICs on InP

The future implementation of powerful Full Services Access Networks (FSAN) will require millions of low cost full-duplex WDM transceivers (TRx) to receive and transmit optical data over a single fibre in each subscriber home. A large cost reduction for commercial production of those modules is currently expected with the imminent availability of photonic integrated circuits (PICs). The development of TRx PICs is therefore one of HHI's key targets.

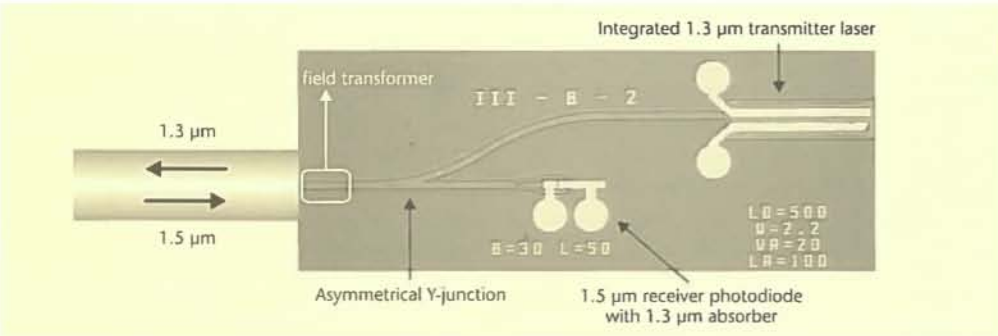

Fig. 1:
Layout of the 1.3/1.5 μm TRx PIC

Figure 1 shows the layout of the projected 1.3 μm/1.5 μm TRx PIC, which consists of a spot size converter (SSC) at the input/output port, an asymmetrical Y-junction for wavelength separation, a transmitter laser (DFB), and a 1.5 μm photodiode for signal detection (including a 1.3 μm waveguide absorber for optical crosstalk suppression). The development of reproducible integration technology and the fabrication of the integrated building blocks were the main tasks this year, which concluded with the following results:

Integration of SSC and Y-junction: This passive network with an asymmetrical Y-junction and an integrated SSC is based on a specially designed rib waveguide layer stack. Overall insertion losses of less than 9 dB (transmission path) and 5 dB (detection path) have been measured with a butt-coupled fibre, with vertical and lateral alignment tolerances less than ±1.5 μm.

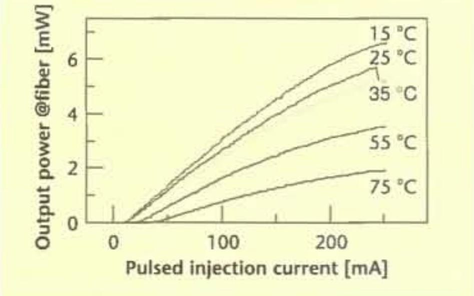

Fig. 2:
P-I characteristics of the 1.3 μm DFB laser with integrated Y-junction

Integration of Y-junction and laser: Qualified 1.3 μm ridge waveguide DFB laser structures from Infineon Technologies have been integrated using selective area MOVPE regrowth of the waveguide and photodiode layer stack. The characteristics of the integrated lasers are almost the same as those of comparable commercially fabricated discrete devices (Fig. 2).

Integration of Y-junction, 1.3 μm absorber, and 1.5 μm photodiode: These integrated subcomponents have external responsitivities between 0.3 and 0.4 A/W with a tapered fibre. The passivated photodiodes have low dark currents at room temperature (typically below 700 pA at –5 V, as shown in Fig. 3) and capacitances below 1 nF, with 3 dB bandwidths less than 4.5 GHz at -5 V.

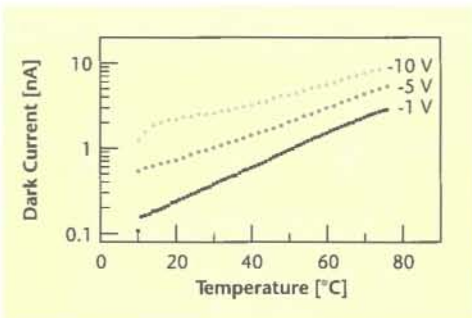

Fig. 3:
Dark current characteristics of the integrated 1.5 μm photodiode at different temperatures and bias voltages

After this successful integration of all the TRx PIC sub-elements into important PIC building blocks, the fabrication of the complete TRx PIC will follow. The first complete PICs will be available next year.

This work is performed under subcontracts with Infineon Technologies and Bosch Telecom under the KomNet project, funded by the German BMBF.

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Low Crosstalk DFB Laser Arrays as WDM Light Sources

Monolithically integrated single mode laser arrays are of increasing interest for WDM transmitter applications, since they are easy to mount and temperature control during operation is also easy. However, as lasers are both temperature sensitive and heat sources, thermal crosstalk is a serious issue, especially if the individual lasers are to be operated arbitrarily and independently from each other.

If more than one laser on a chip operates at the same time, thermal crosstalk becomes a serious problem; e.g. the emission wavelengths change. This restricts their application in WDM systems to two cases: either the laser array functions as a selectable source with only one laser active at a time, or all lasers operate all the time at constant powers. The crucial requirement is to keep the absolute heat load of each laser constant over time.

Our goal is to develop an array of four lasers that can be operated in any eligible configuration and that allows for any laser to be arbitrarily switched on and off without affecting the other lasers.

It is common knowledge that the influence of a heat source decreases with increasing distance. This led us to the new chip design which is depicted in Fig. 1. The basic idea is to place the four lasers at the corners of a square chip.

We integrated eight lasers at six different wavelengths, indicated by numbers 0 to 5 in Fig. 1. These numbers correspond to the WDM channel numbers. The channels of interest are numbers 1 to 4. The two extra lasers (0 and 5) cover two additional channels at either end of the spectrum to account for technological tolerances. This leads to three series of four lasers each: 0 - 3 (white series), 1 - 4 (grey series) and 2 - 5 (black series). Each series of lasers has its own waveguide combiner network to an individual output port. Whichever series we choose, there is always one laser at each corner of the chip. This increases the distance of the lasers to the maximum for the given chip size. In this case the chip measures 3 mm x 3 mm.

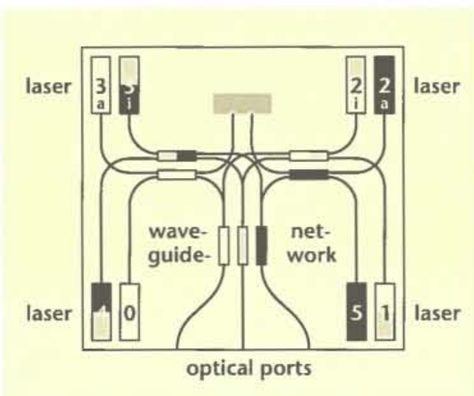

Fig. 1: Chip design of a four-wavelength transmitter PIC for wave division multiplexing, comprising eight lasers and a combiner network based on MMI couplers

We measured the thermal crosstalk by driving one laser as a test device slightly above threshold and monitoring its wavelength, while at the same time increasing the drive current of another laser at the opposite corner of the chip [1]. The dashed line in Fig. 2 shows the result. At a dissipated heat power of 500 mW the wavelength of the test laser is shifted by 200 pm. This is 25% of a 100 GHz channel spacing and is therefore still far from satisfactory.

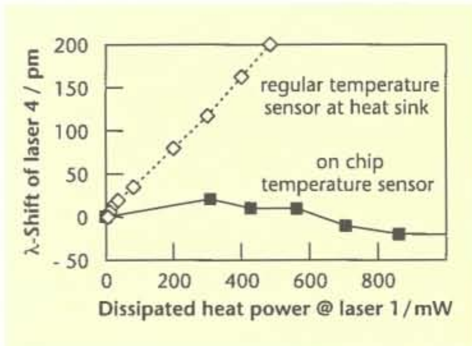

Fig. 2: Results of thermal crosstalk measurements with and without the on-chip temperature sensor

The breakthrough in the development of a low crosstalk laser array was the integration of a heat sensor on the chip. We use a 100 Ω platinum stripe resistor, which can easily be connected to commercial temperature control devices. If the Pt stripe is placed in the middle of the chip and is used to control the chip temperature in place of the usual thermistor on the copper heat sink, the thermal crosstalk is reduced by at least one order of magnitude, as shown by the solid line in Fig. 2.

[1] F. Fidorra et al., "Thermal crosstalk of integrated multiwavelength transmitters", Proc. 16^{th} IEEE Internat. Semicond. Laser Conf., Nara, Japan, 149 (1998).

Frank Fidorra (Fidorra@hhi.de)

Technology of High Performance InGaAsP-InP-RW-DFB Lasers and InGaAsP-InP-BH Lasers

High performance 1.55 µm and 1.3 µm lasers are key components of optical networks. At HHI, ridge-waveguide (RW) distributed feedback (DFB) and buried heterostructure (BH) lasers are being developed for a variety of applications, e.g. transmitters as single devices or transmitters integrated as parts of photonic integrated circuits (PICs).

RW-DFB lasers

RW lasers are well known for their relatively easy fabrication technology and their unproblematic aging behaviour. High power performance can also be achieved if lateral mode instability, in which there is an undesirable lasing action at a second lateral mode, can be avoided. Hence we design the heterostructure layout and stripe width of our lasers to provide single lateral mode emission, particularly at high injection currents [1]. We use a MOVPE-grown strained InGaAsP heterostructure as the active layer. The DFB gratings with $\lambda/4$ phase shift are defined by electron beam exposure and are etched using a reactive ion etching process. After overgrowth of the gratings, the lasers are processed using conventional ridge waveguide technology.

Figure 1 shows the output power characteristic of a 0.4 mm long device. At 20°C more than 50 mW is achieved in CW operation. The lasers show single mode emission up to currents of 350 mA, with side mode suppression ratios better than 40 dB. Output powers above 10 mW can still be obtained at 90°C. Linewidth measurements of these lasers indicated values of around 200 kHz.

BH lasers

Some system applications require transmitter lasers with low power consumption. In these cases BH lasers have advantages over RW lasers, because of their smaller active regions and improved current confinement. At HHI we are currently developing BH lasers using both conventional pn blocking layers and si blocking layers. These developments include improving the heterostructure for high temperature operation as well as improving the fabrication technology to obtain high reproducibility and high reliability.

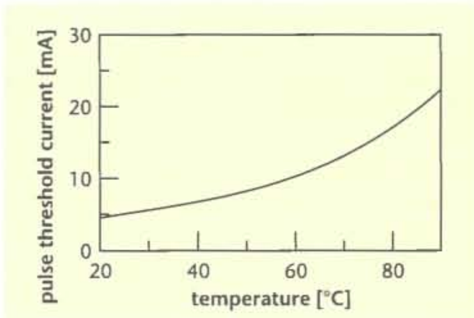

Fig. 2:
Threshold current behaviour of 0.4 mm long, 1300 nm BH-FP lasers with cleaved facets

Figure 2 shows the threshold current behaviour of processed BH lasers with pn blocking layers. Low threshold currents are achieved over the temperature range 20-90°C. Preliminary aging tests showed unproblematic aging behaviour.

[1] M. Möhrle, A. Sigmund, J. Kreissl, F. Reier, R. Steingrüber, W. Rehbein and H. Roehle, "Integratable high-power small-linewidth $\lambda/4$ phase-shifted 1.55 mm InGaAsP-InP-Ridge-Waveguide DFB Lasers", ISCS 1999, Berlin, paper Th A3.1.

Martin Möhrle (Moehrle@hhi.de)

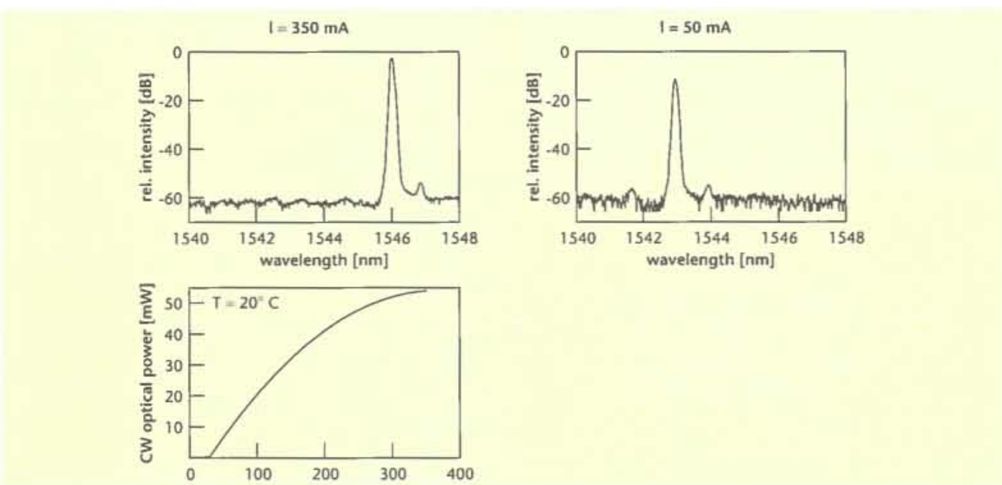

Fig. 1:
Output characteristic of an AR/AR-coated 0.4 mm long, 1550 nm RW-DFB laser

Integrated WDM/PON Overlay Device

A novel component is presented for overlaying a power-splitting passive optical network (PON) in one wavelength band with a wavelength division multiplexing (WDM) comb in another wavelength band. This device consists of an arrayed waveguide grating (AWG) preceded by an integrated power splitter. This concept combines the DEMUX function and the overlay function using different diffraction orders in one and the same AWG. The overlay of eight WDM channels at 1.55 µm wavelength on a 1/8 power split broadcast signal at 1.50 µm wavelength has been demonstrated.

Upgrading an existing star-based passive optical network (PON) carrying broadcast services by adding a wavelength division multiplexing (WDM) overlay offers additional features (e.g. privacy) and better exploits the huge fibre capacity [1].

Several integrated devices for this application have previously been published [2-4], including some by the present authors. Here we introduce a novel approach utilising a specially designed AWG component preceded by a distributing star. It evenly splits the light signal of a broadcast wavelength received at one input port among N output ports, and also overlays N demultiplexed WDM channels.

The design (Fig. 1) makes use of the basic imaging and wavelength dispersion properties of the AWG between inputs and outputs. The well known demultiplex function between one input port and N output ports for wavelengths $\lambda_1 ... \lambda_N$ in the WDM band uses grating order m. The overlay function for a broadcast signal at wavelength λ_b onto these N output ports utilises the imaging from properly positioned N input ports, with the same or a different grating order m+k (k = 0, ±1, ±2, ...) is used. The preceding 1/N power splitter for broadcast signal distribution is also integrated on the wafer, and hardly increases the chip size.

The device is realised in planar silica technology. The AWG has been designed with a grating order m = 68 for the WDM band and a corresponding free spectral range of about 22.8 nm. The order used for λ_b = 1.50 µm is m+k = 70 (k = +2). There are 95 waveguides in the array.

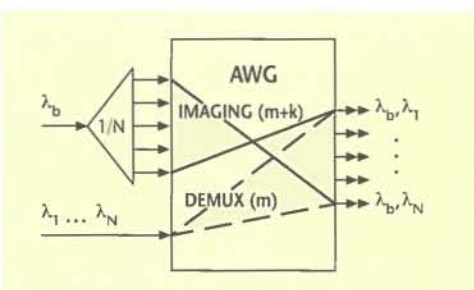

Fig. 1: Basic design of a broadcast PON/WDM overlay device using the demultiplexing and imaging properties of an AWG with different grating orders m and m+k

Figure 2a shows the measured 8-channel WDM demux function around 1.55 µm with 200 GHz channel spacing. The 3 dB working range is about 80 GHz (0.65 nm). An insertion loss of 3.0 dB, including fibre-waveguide coupling, was achieved, with crosstalk less than –25 dB.

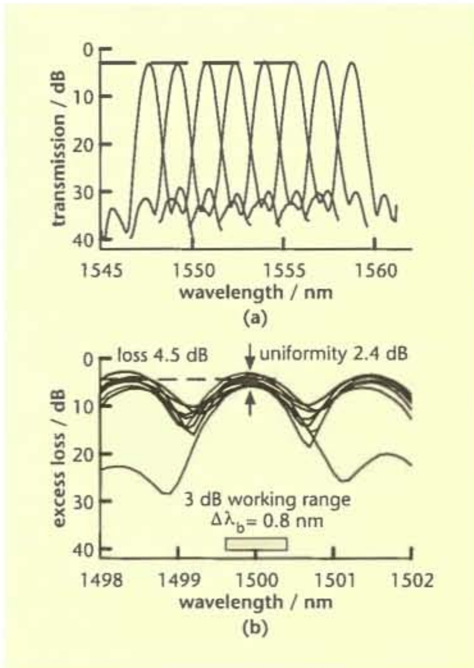

Fig. 2: Measured transmission and loss spectra of the DEMUX / OVERLAY MUX component (m = 68) (a) Transmission in the 1.55 µm WDM band (b) Excess loss of the distribution system for broadcast wavelength λ_b around 1.50 µm

Figure 2b shows the distribution behaviour at the same eight output ports for a broadcast wavelength around 1.50 µm, which was launched into the star coupler input. An average loss of 4.5 dB is measured at 1.50 µm with a power uniformity of ±1.2 dB. The 3 dB working range in the broadcast band is about 100 GHz (0.8 nm).

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[3] G. Przyrembel et al., Electron. Lett., vol. 34, No. 3, pp 263-264, 1998.

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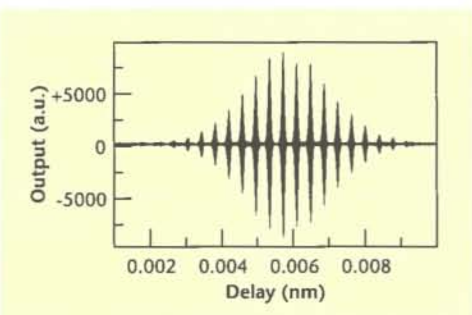
Arrayed-Waveguide Grating Demultiplexer with Variable Centre Frequency and Transmission Characteristic

A tunable arrayed-waveguide grating (AWG) demultiplexer is presented. The device exhibits new functionalities, especially tunable centre frequency and a variable transmission characteristic. The measured crosstalk was lower than –30 dB.

It is desirable to use the large parallel capability of optical wavelength division multiplexing (WDM) techniques to increase the capacity of optical transmission systems. One of the key devices required for WDM systems is a filter with variable bandwidth and tunable centre frequency.

We have successfully realised a new tunable WDM demultiplexer using an AWG with phase controllers. The demultiplexer is used to demultiplex a 4-channel WDM spectrum at 1.5 µm wavelength. The device has high functionality and good optical performance. The measured crosstalk of the optimised demultiplexer is better than -30 dB, the 3 dB bandwidth can be varied from 87 to 212 GHz, and the centre frequency can be tuned over a 250 GHz range with fixed bandwidth. An average loss of 7 dB was measured for the 1.5 µm signals.

The AWG and the waveguides were fabricated using optical lithography and reactive ion etching on SiO_2-GeO_2 layers deposited by flame hydrolysis. The optical path phases of the AWG can be individually controlled by thin film heaters formed on the arrayed waveguides, and were measured in situ using a Fourier low coherence interferometer. A measured interferogram is shown in Fig. 1. The interferogram consists of sharp fringes that are produced by interference between the light that has propagated through the AWG and the light in a delay line arm in the interferometer. A Fourier transformation converted the data to the frequency domain for the figure.



The design of the AWG is based on beam-propagation method (BPM) simulations. It consists of 25 regularly arranged waveguides with constant path length difference $\Delta L = m \cdot \lambda / n_{eff}$, where λ is the central wavelength, n_{eff} is the effective index of the waveguides and $m = 241$ is the grating order. The designed channel spacing is 200 GHz and the corresponding free spectral range is 800 GHz.

The optical phases were controlled individually by thermo-optical (TO) Ti/Pt thin-film heaters. The rise and fall times for a phase shift of 2π were both 1 ms. The measured next-neighbour crosstalk was -30 dB with thermo-optical phase compensation and -20 dB without. This improvement in crosstalk agrees quite well with our theoretical calculations. Figure 2 shows the measured centre frequency tuning range of the AWG with a fixed 3 dB bandwidth. The phases in the arrayed waveguides were shifted by the same amount. By introducing a phase variation in the form of a sinc function it was possible to obtain a flat top intensity distribution at the output ports of the AWG [1].

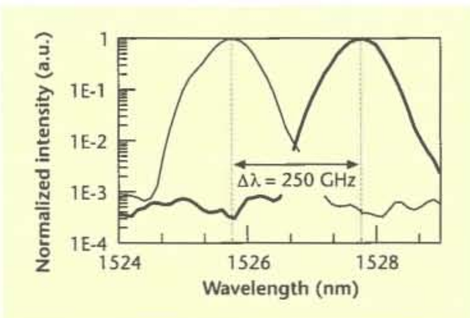


Fig. 2:
Measured interferogram of an AWG

The tunable AWG demultiplexer has high functionality and good optical performance. It is expected that it will find various applications in the field of optical telecommunications.

This work is supported by the German Ministry of Education, Science, Research and Technology (BMBF) under grant number 01 BS 609.

Fig. 1:
Measured tuning characteristic of a TO-AWG

[1] E. Pawlowski et al., Proc. ECIO 99, pp. 207-210, 1999.

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Polymer-Based Arrayed Waveguide Filters

Polymer-based arrayed waveguide grating (AWG) filters have been fabricated using a newly developed material system based on fluorinated polycyanurate. The measured optical waveguide loss is less than 0.4 dB/cm at 1550 nm wavelength. Using this material, NxN AWG wavelength routers and 1xN AWG MUX/DEMUXes with up to 32 channels at 100 GHz channel spacing were fabricated and characterised.

Wavelength multiplexer/demultiplexer (MUX/DEMUX) devices based on arrayed waveguide gratings (AWG) are key optical components for dense wavelength division multiplexed (DWDM) optical telecommunication systems. Though this class of devices has been the domain of silica technology, polymer materials have been receiving increasing attention in recent years, largely because they offer potentially lower fabrication costs. From the materials point of view, polymers have a thermo-optic (TO) coefficient (dn/dT) ten times greater than that of silica, which can be beneficially exploited for spectral tuning over a comparatively wide wavelength range with reasonable heating power. This feature, along with low thermal conductivity, also allows the implementation of efficient TO switches, which eventually may be integrated together with AWG structures to produce an all-polymeric add/drop multiplexer chip.

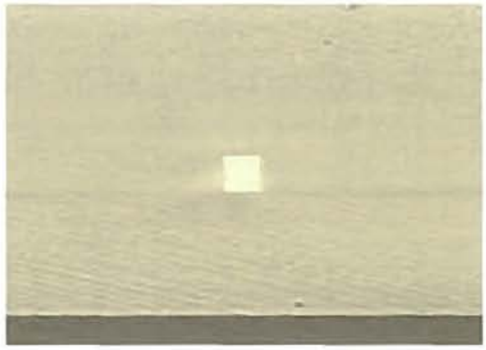

Fig. 1: End face of a polymer waveguide with 6x6 μm^2 core (loss less than 0.4 dB/cm at 1550 nm)

Some key desired properties of organic optical waveguide materials are, amongst others, low propagation losses at the operating wavelength window around 1550 nm, high thermal and environmental stability, very low birefringence values, and precise adjustability of the refractive index n. At the same time, for compact waveguide devices it is desirable to have a relatively wide index tuning range (Δn values of 0.02 or more).

In co-operation with the Fraunhofer Institute for Reliability and Microintegration (FhG IZM), Berlin-Teltow, a material system based on fluorinated polycyanurate was developed that has an optical loss of less than 0.3 dB/cm at 1550 nm wavelength together with high thermal stability ($T_g > 250°C$). In addition, a refractive index variation up to $\Delta n = 0.03$ can readily be obtained. Based on this new material system, polymer waveguides were fabricated using conventional photo-lithography and reactive ion etching (RIE) techniques. The end face of a polymer channel waveguide is shown in Fig. 1. The waveguide has an optical loss of typically less than 0.4 dB/cm at 1550 nm.

A polymeric NxN AWG wavelength router and a 1xN multiplexer/demultiplexer (MUX/DEMUX) were fabricated and characterised. These had up to 32 channels at 100 GHz channel spacing in the 1550 nm window, in accord with the ITU standard. Figure 2 shows the measured spectral response of an 8x8 AWG router with a channel spacing of 200 GHz based on the fluorinated polycyanurate material system. This device has an insertion loss in the range 5-7 dB and a crosstalk of less than -27 dB.

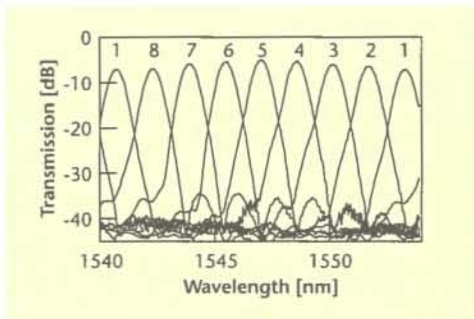

Fig. 2: Spectral response of a polymer-based 8x8 AWG

Optical add-drop multiplexers (OADM) consisting of AWG-type filters and optical space switches will play a key role in advanced DWDM networks. The polymeric AWG developed here is considered to be an important building block for OADM components, in which these structures will be combined with digital-optical switches (DOS), which are also under development. The common material basis allows the monolithic integration of OADM chips.

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Thermo-Optical Switches using Hybrid Polymer/Silica Technology

A hybrid polymer/silica technology concept is investigated that combines the advantages of the ultra-low loss of silica waveguides and the low power consumption of polymer thermo-optic switches. As one possible approach, a vertically coupled structure has been realised. This vertical integration concept extends the optical interaction to a third dimension and thus increases the density of optical devices on the same substrate, a prerequisite for the implementation of large space switching matrices.

It is well known that SiO_2 waveguides have very low optical loss in the 1550 nm wavelength window. On the other hand, thermo-optic (TO) switches based on SiO_2 suffer from rather high electrical switching power consumption, in contrast to polymer-based TO switches. Therefore, a hybrid polymer/silica technology concept is proposed, in which the planar SiO_2 waveguide is used only as an optical transport layer and the planar polymer waveguide is used for the switching function. A vertical coupling scheme has been adopted to realise these hybrid devices. This integration concept extends the optical interaction to the third dimension and hence increases the density of optical devices that can be accommodated on the same substrate, which is important for the realisation of large switching matrices. A basic prerequisite for this approach is the availability of polymers with refractive indices matched to that of silica. Such materials are developed by the FhG IZM, Berlin-Teltow, and were used in this work.

A polymer/silica vertical coupled switch (VCS) is shown in Fig. 1. Optical waveguide structures based on silica-on-silicon technology were fabricated using a common test mask set provided by the collaborating partner, Alcatel SEL, Stuttgart. The thickness of the upper cladding layer needs to be controlled accurately to guarantee the designed switching behaviour. In a second step the polymer guiding layer was spin coated and etched by reactive ion etching (RIE) to form polymer channel waveguides. Finally, a polymer top cladding layer was deposited on the polymer waveguides, and heating electrodes were fabricated. The waveguide parameters, such as the refractive indices and dimensions of each layer, the crossing angle, and the interaction length between the silica and polymer waveguides, were designed using the 2D finite element method and the 3D coupled mode method. The waveguide parameters are designed so that there is no optical coupling between the SiO_2 and the polymer waveguides (bar) in the initial state (i.e. when the electrode is not heated). When the electrode is heated, the optical power in the SiO_2 waveguide will be completely coupled to the polymer waveguide (cross-state).

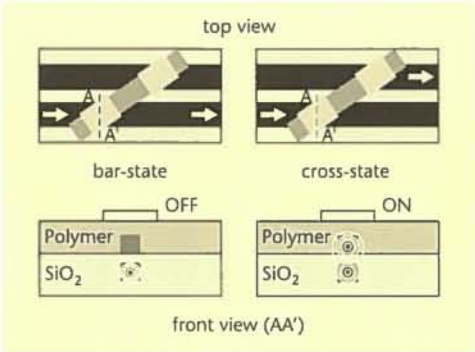

Fig. 1:
1x2 polymer/silica vertical coupled switch (VCS)

A 1x2 basic switching unit with two vertically coupled switching elements was designed and tested (Fig. 1). When the electrodes are not powered (OFF), input light coupled to the lower silica waveguide will propagate through this waveguide. When the electrodes are sufficiently powered (ON), the input light is coupled to the polymer waveguide in the first element and coupled back to another parallel silica waveguide in the second element.

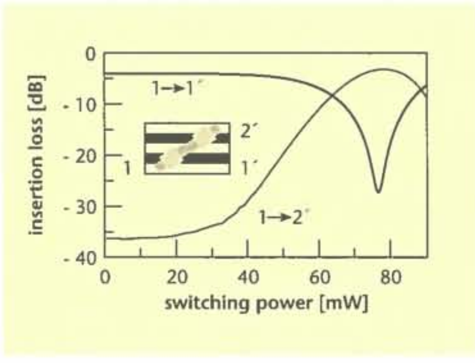

Fig. 2:
Switching characteristic of 1x2 VCS at 1550 nm

Preliminary results are that the crosstalk is below -20 dB and the insertion loss is less than 4 dB at 1550 nm. The switching power was less than 80 mW (Fig. 2). Currently, 2x2 and 1x8 vertical coupled switches (VCS) are under development.

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Novel Optical Pick-Up Concept based on Diffractive Optical Elements

We report on diffractive optical elements that have been developed for a new integrated optical pick-up unit for double-layer DVDs. Multi-level diffractive optical elements and binary high frequency gratings were successfully employed in the proposed system.

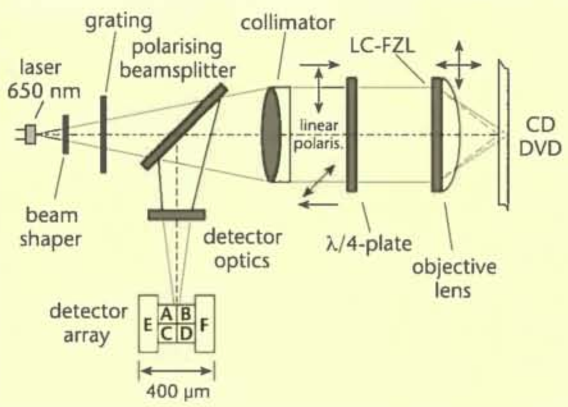
With their advantages of small size, light weight and arbitrary wave front generation, diffractive optical elements (DOEs) have enormous application possibilities.

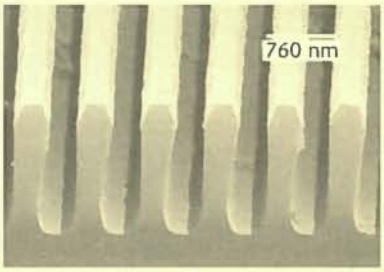
An example is in the field of optical disk systems, where DOEs give systems with great compactness, light weight and complex functions with diffraction-limited performance.

The multi-level DOEs were realised in glass using multiple lithographic pattern transfer and ion beam sputter deposition techniques [4].

The diffractive and hybrid elements that were designed and realised for the novel pick-up unit were first tested as single components, and then incorporated in a demonstrator pick-up, which has been set-up by our partners at the Technical University of Darmstadt (Prof. Tschudi group). The measurements showed that, because of their good optical performance, our DOEs are well suited for the implementation in optical DVD pick-up systems.

Left:
Schematic setup of a DVD pick-up





Right:
Polarisation-selective beam splitter realised in quartz glass

The Figure (left) shows the optical configuration of a dual-focus optical DVD pick-up system, in which the variation of the focal length is based on polarisation switching using DOEs and liquid crystals (LC) [1].

Resonance-domain gratings with feature sizes in the sub-micrometre range are strongly polarisation dependent (i.e. the phases and efficiencies of the diffracted orders depend on the polarisation of the incident light). Using direct e-beam writing combined with reactive ion etching, we realised high frequency gratings in quartz glass, with grating periods down to 390 nm. These work as polarisation elements, such as polarising beam splitters or phase retarders (λ/4 plates) [2]. The binary polarising beam splitters are designed to separate the reflected light beams from the two DVD layers, which have different polarisations (TE and TM).

To avoid phase aberrations for the collimator, a hybrid combination of refractive and diffractive optical elements was chosen. This hybrid element collimates the light from a laser diode with wavefront aberrations less than λ/20. Astigmatic detector optics were realised by four-level DOEs mounted in a sandwich configuration [3].

This work was supported by the German Ministry of Education, Science, Research and Technology (BMBF) under grant number 01 BS 609/0.

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[3] R. Steiner et al., EOS Topical Meetings Digest, vol. 22, pp. 246-247, 1999.

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Computer-Generated DOEs with High Optical Efficiency

Various diffractive optical elements (DOEs) have been realised for beam splitting and beam shaping purposes. We report on a beam splitter that was intended to split an incoming laser beam into 40 partial beams of equal intensity and on a pattern generator that produces a given, arbitrary intensity pattern. The diffractive phase elements, with feature sizes down to the sub-micrometre range, were fabricated in quartz glass by microstructuring techniques.

Computer-generated diffractive optical elements are key components for systems and devices where small dimensions and compactness are demanded. Due to their high design flexibility, they play an important role in fields such as optical communications, optical sensor systems, medicine and metrology.

A diffractive optical element is in general a complex pattern of microstructures that can modulate and transform incoming light in a predetermined way. Here we focus on the development of:

a) Beam splitters (BS) designed to split an incoming laser beam into 40 dots of equal intensity (uniformity better than ±3%) arranged equidistantly on a circle. These were realised as binary phase elements.

b) Beam splitters designed to generate a given arbitrary intensity pattern were produced in an eight-level approximation.

The computation of our DOEs was performed using a modified iterative Fourier transform algorithm (IFTA) [1]. The DOEs were fabricated for the visible wavelength region in quartz glass using direct e-beam writing and reactive ion etching. To obtain high efficiencies, the computer-generated holograms were realised as transmissive diffractive phase elements [2].

We achieved a diffraction efficiency (the ratio of the sum of the intensities of the 40 spots to the incoming power) of about 60% for the circular 1:40 beam splitters, which is in good agreement with the computed value of 63%. As shown in Fig. 1, all spot intensities were confined to a range within about ±2.5% of the mean intensity value of 2.4 μW.

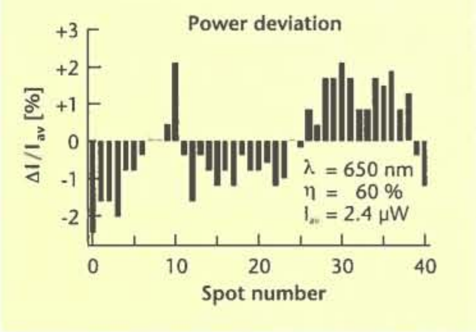

Fig. 1:
Variation of the individual spot intensities of a 1:40 beam splitter

The measured diffraction efficiencies of the eight-level pattern generators were about 81%, which is also close to the theoretical value of 84%. As an example, Fig. 2 shows the diffraction pattern of an eight-level DOE that was designed to create the HHI logo.

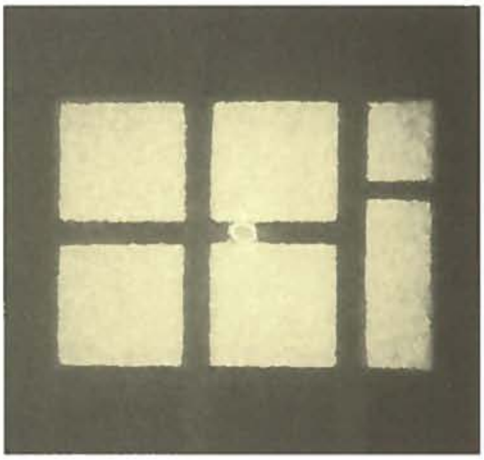

Fig. 2:
Diffraction pattern of an eight-level DOE

The optical characterisations of the pattern generators and binary beam splitting elements showed good agreement with the results obtained from simulations. Even replicated elements, which were realised by an external partner in polymer using simple embossing techniques, also had good optical performance.

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Space-Time Processing

The coming high-level information society in the 21st century is already characterised by an explosive increase in the use of the Internet and mobile communication systems. The challenge is to realise high rate wireless services in a complex and rapidly varying propagation environment, where limited availability of radio spectrum is a major obstacle.

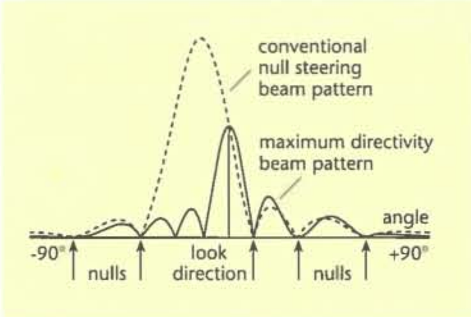
A promising approach to attack the above problems is to use space-time processing (STP) with antenna arrays at the base station. STP combines two signal processing concepts: temporal equalisation and spatial filtering (beamforming). The potential advantages of this approach are significant enough to outweigh the increased hardware requirement for the parallel processing of multiple antenna elements. The primary purpose of beamforming is to improve the signal-to-interference ratio (SIR) by suppressing interfering sources transmitting at the same frequency and in the same time slot. Other potential benefits are increased antenna gain, decreased delay spread and increased immunity to the near-far effect. Moreover, substantial capacity gains are expected with space division multiple access (SDMA), which enables several subscribers to share the same frequency band.

Maximum directivity beamformer

In the DS-CDMA uplink, spatial filtering can easily be incorporated by adding a beamformer [1] to each of the fingers of a RAKE receiver. This is referred to as the 2D RAKE, which can be regarded as a space-time matched filter adapted to the multipath channel. Compared to multiuser techniques, this approach offers a computationally inexpensive and robust means of interference suppression.

For the downlink, users are typically separated by orthogonal Walsh-Hadamard sequences. In the case of frequency selective channels, orthogonality may easily deteriorate because of multipath effects. As for the uplink, spatially resolvable delays and interfering signals can be suppressed by beamforming techniques, thus creating a virtual AWGN channel.

Clearly, the spatial filtering properties of the array depend strongly on the chosen beamforming algorithm. The goal is to suppress both dominant interferers and spatially white background noise, which is due to multiple access interference (MAI), self interference and inter-cell CCI. While dominant interferers can be suppressed by steering nulls, it can be shown [2] that the spatially white interference is minimised by maximising the directivity of the beam pattern.



We propose a new algorithm incorporating both of these spatial filtering aspects [2]. For a given number of nulls, it always yields maximum directivity of the beam pattern (Fig. 1). Furthermore, our approach inherently supports SDMA, which is based on steering nulls of the beam pattern towards undesired users. Provided that the user locations are known (which is an essential prerequisite for SDMA), the null steering approach may be used to separate a number of users sharing the same resources. In this context, the directivity offers a meaningful measure for judging the separability of two users. Moreover, suppression of interferers with large angular spreads is catered for by steering broad nulls of the beam pattern [2]. Thus, the proposed technique possesses the robustness and simplicity essential for practical implementation.

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

[1] Holger Boche and Martin Schubert, "Linear antenna array beamforming with interpolation methods", Frequenz, vol. 53, pp. 73-83, March 1999.

[2] Holger Boche and Martin Schubert, "Investigation of up-link and down-link performance of directivity controlled constrained beamforming algorithms for CDMA-based systems", Proc. CIC 99, Seoul, Korea, Sept. 1999.

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Calibration of Antenna Arrays for Third Generation Mobile Communication Systems

As well as classical phone services, more and more high rate data services will be offered in third generation cellular mobile communication systems. Mobile Internet access with full multimedia capabilities is an important goal. Because of the limited frequency spectrum resources, methods of enhancing spectral efficiency must be used. A promising technique is to use smart antennas, which are antenna arrays whose elements are individually controlled by digital signal processors.

A possible way to use smart antennas to obtain higher spectral efficiency in mobile communication systems is offered by the Space Division Multiple Access (SDMA) concept. The operating algorithm of SDMA consists of two fundamental steps. First, the directions of the mobile stations are determined using Direction of Arrival (DoA) estimation methods on the array output signals. In the second step, a number of radiation characteristics are generated and applied simultaneously to the antenna array by digital beamforming devices. Each radiation characteristic serves one mobile station (or one group of mobile stations), and suppresses radiation or reception in directions of the other mobile stations by steering nulls towards them. This allows different mobile stations in a cell to use the same frequency channel and spreading code sequence, and thereby increases the system capacity.

The achievable gain with this concept depends strongly on the accuracy of the DoA estimation and the precision of the null steering. The properties of the actual antenna arrays have an important influence on these matters – array signal processing methods are usually developed for ideal antenna arrays, but with real antenna arrays there are inaccuracies and other disturbing effects. The signal processing methods are sensitive to these effects, so that it is necessary to calibrate the antenna arrays in real mobile communication systems.

The basis of the calibration procedure is the error model, which describes quantitatively the inaccuracies and disturbing effects of the antenna array. The parameters of the error model are determined in the working communication system under real environmental conditions.

The customary standard error model includes the effects of mutual coupling of the antenna elements as well as their gain and phase errors. These effects occur to some degree in all kinds of antenna arrays. In microstrip antenna arrays there are additional disturbances caused by the bounded substrate areas. However, microstrip antenna arrays are very attractive for applications in mobile communication systems due to their low manufacturing costs and light weight.

Experimental antenna array in the anechoic measurement chamber

From measurements on experimental microstrip antenna arrays we have developed an extended error model that includes the disturbing effects of the substrate edges of microstrip antenna arrays in addition to the effects included in the standard error model. It gives a more accurate calibration of microstrip antenna arrays, and leads to higher space diversion gains in mobile communication systems. Measurements and simulations of experimental antenna arrays indicate that performance gains can be expected with the extended error model.

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

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Optimum Beamforming for two dimensional Antenna Arrays

Smart antennas are discussed as one of the key components for coping with the challenges of future mobile communication systems. They support an increased number of subscribers through spatial separation, and use spatial filtering to generate a more benign communication channel. The performance increase to be expected depends largely on how accurately the beam pattern can be adapted to the actual interference pattern. In picocell and indoor environments, where the directions of arrival differ in both azimuth and elevation, the beam pattern must be controlled in both directions by using a two dimensional antenna array.

The rapidly increasing number of subscribers, together with increasing demand for heterogeneous broadband services and applications, provide the main challenges for future mobile communication systems. Given the limited spectrum resources, it is generally expected that the use of smart antennas will increase the overall system capacity and performance. Smart antennas increase the system capacity in several ways: spatial separation of different users allows an increased number of users in the same frequency band, and spatial filtering effectively reduces the interference caused by multipath propagation and multi-user access.

The performance increase to be expected with smart antennas is highly dependent on how accurately the beam pattern can be adapted to the actual interference pattern. In picocellular and indoor environments the signals arrive at the base station with different azimuth and elevation angles. To achieve maximum performance increase, the beam pattern has to be controlled in both directions using a two dimensional array, as shown in Figure 1.

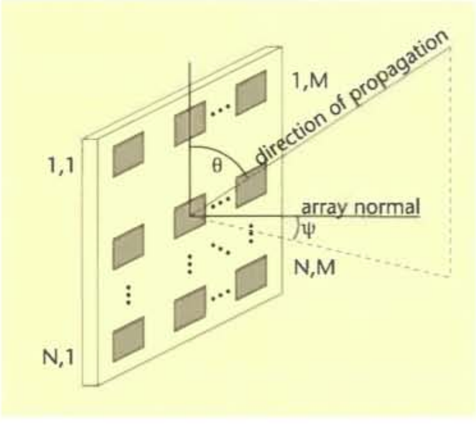

Fig. 1: **Two dimensional antenna array with MxN antenna elements**

The beam pattern of this array geometry is the product of those of two orthogonal linear antenna arrays. In [1] an optimum beamforming algorithm for two dimensional antenna arrays was developed. It gives optimum beam steering and interference cancellation for nearly arbitrary directions of the desired and interfering signals. Figure 2 shows the beam pattern of a 4x4 antenna array.

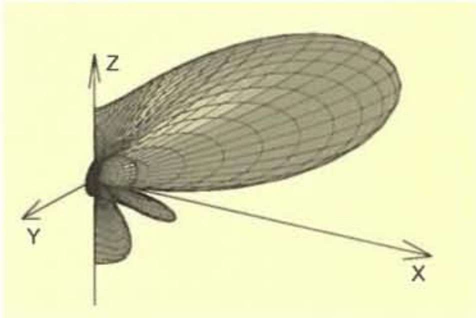

Fig. 2: **Beam pattern of a 4x4 antenna array, in which the main beam and three nulls are steered**

Compared with linear antenna arrays, two-dimensional beamformers show completely new behaviour and require new beamforming algorithms. With linear arrays the number of placeable nulls depends directly on the number of array elements, but with two dimensional arrays the maximum number of nulls depends not only on the number of elements but also on the positions of the nulls. For an MxM antenna array this maximum number can vary from M^2 nulls in the best case down to M nulls in the worst case. A relation between the maximum number of nulls and their positions is not known. To avoid this problem a robust beamformer can be used, in which the beam in the azimuth plane is formed with a maximum directivity beamformer and the beam in the elevation plane is formed with a phased array.

The work presented here was performed in cooperation with the Ilmenau Technical University, and was supported by the German Federal Ministry of Education, Science, Research and Technology (BMBF) under grant number 01 BK 611/3.

[1] T. Kuhwald and H. Boche, "A constrained beam forming algorithm for 2D planar antenna arrays", Proc. IEEE Vehicular Technology Conference '99, pp. 1-5, Amsterdam, September 1999.

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Characterisation of Handover Traffic in Cellular Mobile Communication Systems

For fixed telecommunication networks the conditions for the validity of the Erlang-B loss formula are fully met. However, for mobile communication systems some of the required conditions are not satisfied. Therefore, significant differences between the blocking probabilities obtained using the Erlang-B loss formula and those obtained from simulations can be expected.

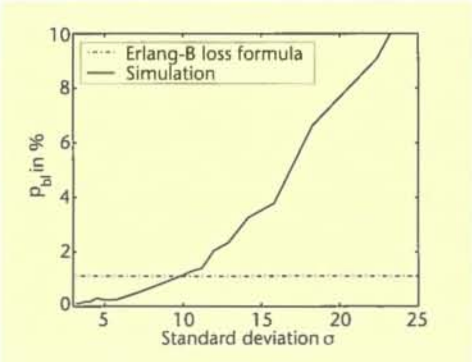
A fixed telecommunication system can be considered as a queuing system with limited storage capacity (loss system). The arrival process is formed by the arrival of new calls, for which a Poisson process can be assumed, as acknowledged in the literature. The call holding time, which in fixed networks is identical to the channel holding time and also to the service time of the queuing system, is assumed to be exponentially distributed. If we have c servers, which is the maximum number of available channels (lines) of the system, this constitutes a *M/M/c/c* queue. For this type of queue the Erlang-B loss formula can be used to calculate the blocking probability.

The following requirements are necessary for the Erlang-B loss formula:

1. Poisson arrival process
2. Any service time distribution with finite mean.

The last item is especially important when considering mobile communication systems, since in this case we have several cells and the channel holding time is not identical to the call holding time. The channel holding time in mobile communication systems is often only a fraction of the call duration, depending on the mobility. Also, the channel holding time distribution is generally not exponential. Fortunately, the probabilities that the system is in specific states are insensitive to the distribution of the service time in the equilibrium state [1]. The distribution of the service time influences mainly the time required to reach the equilibrium state. We have found that this time will be longer for distributions with large variances.

Another factor with mobile systems is the nature of the arrival process at a cell. Because of the cellular structure of mobile communication systems, handovers must be considered. Thus, the total arrival process at a cell is composed of the new call arrival process, which is Poisson, and the handover arrival process, which is generally not Poisson. In the figure the influence of an arrival process (with a gamma distribution of the interarrival time) on the blocking probability is shown. If the standard deviation of the arrival process is larger than that of the Poisson process, the blocking probability is underestimated by the Erlang-B loss formula; otherwise it is overestimated.



Blocking probability as a function of the standard deviation of the arrival process (arrival rate $\lambda = 0.1s^{-1}$, service rate $\mu = 1/90s^{-1}$, number of channels c = 16)

In our work analytical techniques are derived to characterise the handover traffic. Conditions for good approximations by a Poisson process are also derived.

The work presented here was performed in cooperation with the Ilmenau Technical University, and is supported by the German Federal Ministry of Education, Science, Research and Technology under grant number 01 BK 611/3.

[1] Medhi, J., "Stochastic Models in Queueing Theory", San Diego, Academic Press, Inc., 1991.

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Influence of Biased Sampling on Signalling Traffic

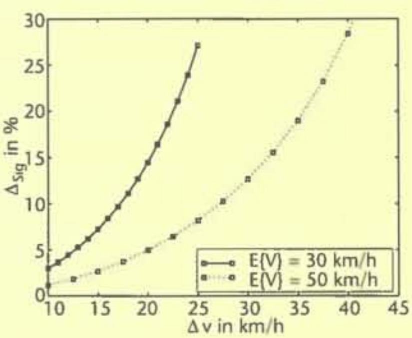
It has long been known that the velocity distribution of boundary-crossing subscribers is different from that of all other subscribers (biased sampling). We investigate the implications of this phenomenon for signalling traffic. Our results indicate that biased velocity sampling has a significant impact on the system behaviour of mobile communication systems. Hence it is important to use the biased sampling model for predicting the performance of future systems.

Currently, performance prediction of fixed telephone networks is nearly completely understood. However, significant differences are obvious in mobile networks, such as the in-call behaviour of mobile subscribers and their mobility behaviour (which causes frequent location changes and consequently handovers and location updates). To understand these new effects, mobility models are needed, e.g. to map user mobility into signalling traffic (handover and location update signalling).

The channel holding time, which is defined as the time a new call or handover call occupies a channel in a radio cell, is a very important parameter for estimating the performance of mobile communication systems. Each establishment of a call, each handover and each call termination generates a number of signalling messages. Thus, the amount of signalling traffic will be inversely proportional to the mean channel holding time. In fixed telephone systems the channel holding time is identical to the call duration, but in mobile communication systems the channel holding time is often only a fraction of the call duration. Therefore the distribution of the dwell time (cell residence time) is required. The dwell time distribution can be obtained from mobility models, but with a high computational effort involving statistical averaging.

Another possibility for describing subscriber mobility is to use analytical dwell time models, which represent a higher level of abstraction than mobility modelling. This method is fast and is useful for fundamental studies. In [1] the dwell time distribution was derived for a specific mobility model, but neglecting the biased sampling of the velocity. In the literature, it has been observed that a subset of mobiles (e.g. those crossing the cell boundary) has a different velocity distribution from all other subscribers. Thus, the velocity distribution at the cell boundary favours higher velocities. This phenomenon has a significant impact on the signalling traffic. In our work, the Hong-Rappaport model was modified to include this phenomenon.

In the figure the predicted signalling traffic at different mean velocities is compared with the predictions of the Hong-Rappaport model without biased sampling. The figure indicates that large standard deviations of the velocity or low mean velocities cause large differences between the predicted amounts of signalling traffic with and without biased velocity sampling. Thus, in contrast to the analytical calculations of Hong (without biased sampling), we calculate a significant increase of signalling traffic. As an example, an increase of signalling traffic of about 27% is obtained with the parameters: mean call duration 180 s, mean velocity 30 km/h, and standard deviation 25 km/h. A complete discussion can be found in [2].



Increase of signaling traffic if the biased sampling of the velocity is neglected as a function of the deviation of the velocity

The work presented here was performed in cooperation with the Ilmenau Technical University, and is supported by the German Federal Ministry of Education, Science, Research and Technology under grant number 01 BK 611/3.

[1] D. Hong and S. S. Rappaport, "Traffic Model and Performance Analysis for Cellular Mobile Radio Telephone Systems with Prioritized and Nonprioritized Handoff Procedures", IEEE Trans. Vehic. Technol., vol. 35, pp. 77-92, August 1986.

[2] E. Jugl and H. Boche, "Influence of Biased Sampling on Mobile Communication Systems", accepted at the IZS2000, Zürich, February 2000.

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Analysis of Spreading Sequences for CDMA Systems

Direct sequence CDMA (Code Division Multiple Access) is emerging as the dominant radio access technology for the next-generation regional and global wireless standard. This is primarily due to its potential for high spectral efficiency. This capacity advantage, together with other features such as soft capacity, robustness against multipath effects, and the potential use of advanced antenna and receiver structures, have contributed to growing interest in this technology.

The choice of the sequence for CDMA systems is important for their robustness to both multipath and multiuser interference. To combat multipath interference, each sequence in the set must be easily distinguishable from a time-shifted version of itself, and to combat multiuser interference, each sequence must be easily distinguishable from all other sequences in the set. Multipath interference occurs in the mobile outdoor and indoor radio environments, and multiuser interference is important for the multiple access capability of the communications system.

In a synchronous CDMA (S-CDMA) system, all users are in exact synchronism in the sense that not only are their carrier frequencies and phases the same, but also their data symbols are aligned in time. Consequently, to minimise multiuser interference in a S-CDMA system, it suffices for the designer to consider inner products of each pair of spreading sequences in the set.

Unfortunately, this approach is not sufficient in CDMA-based mobile communication systems, since the synchronism is in general lost due to the multipath radio environment. These circumstances are further complicated in the many-to-one up-link from the mobile users to the base station, since the signals travel different path lengths from the spatially separated transmitters to the base station, and therefore arrive with different delays. To guarantee good performance of such asynchronous systems, the designer must construct a set of sequences having good aperiodic correlation properties. Moreover, it may be shown that the worst interference in asynchronous CDMA-based systems with single-user decoders generally occurs for the largest aperiodic correlations.

To evaluate aperiodic correlation properties of spreading sequences, l^2-criteria of goodness are usually used. In [1], a direct evidence is given to demonstrate the utility of l^2-criteria in the context of CDMA performance. Unfortunately, despite having expanded much effort for many years, no systematic methods are known for constructing sequences with good aperiodic correlation properties. Also, because of the computational complexity, complete numerical search procedures are not feasible for interesting sequence lengths and for large numbers of sequences.

So far research activities at HHI have focussed on analytical methods for investigating the well known criteria of goodness for assessing the aperiodic correlation properties of sequences, including the maximum- and l^2-criteria, the noise enhancement factor and the peak factor. Among other things, upper and lower bounds of the l^2-criteria have been proved for the well known Frank-Zadoff-Chu sequences with perfect periodic autocorrelation functions. These bounds show that, under certain constraints, the FZC-sequences may also have excellent aperiodic correlation behaviour. Furthermore, the behaviour of generalised binary Rudin-Shapiro sequences in terms of the l^2-criteria could be characterised completely. These sequences are of interest due to their close connection with the Golay sequences proposed for random access channel (RACH) preamble signals in the universal mobile telecommunication system (UMTS).

This work is supported by the German Ministry of Education, Science, Research and Technology (BMBF) under grant number 01 BK 611/3.

[1] S. Stanczak and H. Boche, "Aperiodic Properties of Generalized Binary Rudin-Shapiro Sequences and some Recent Results on Sequences with a Quadratic Phase Function", accepted for 2000 International Zurich Seminar on Broadband Communications, February 15-17, ETH Zurich, Switzerland.

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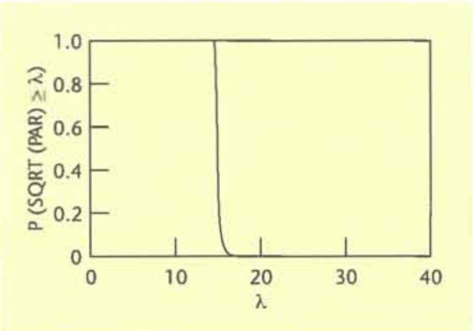
Analysis of OFDM Systems

Orthogonal Frequency Division Multiplex (OFDM) is seen as a key technology in future Wireless Local Area Networks (WLAN). It has also been adopted for Digital Audio Broadcasting (DAB) and Digital Video Broadcasting (DVB). A major problem in OFDM systems is the unfavourable Peak-to-Average Power Ratio (PAR) of the transmitted signal. The PAR statistics of OFDM signals have been investigated for common modulation schemes, and new accurate upper bounds have been derived.

Developed by Weinstein and Ebert in the early seventies, OFDM has attracted great attention in several broadband wireless access scenarios due to its ability to combat multipath fading in frequency selective channels with reasonable complexity. OFDM transmits several bits in parallel and prolongs the bit duration to an OFDM symbol interval. Compared to single carrier systems, the bandwidth is maintained by using mutually orthogonal subcarriers which are properly spaced in the frequency domain and the spectral efficiency is even higher. If the number of subcarriers is sufficiently large, the bandwidth of each sub-band is small compared with the channel bandwidth, so that it may be viewed as narrowband and equalised by a simple multiplication.

However, it is well known that multicarrier signals have very large peak values compared with their mean values. This is measured in terms of the PAR statistics, which form a key parameter in OFDM systems, since it weighs power efficiency against bit error rate and out-band distortion. It is worth mentioning that the PAR problem is of wide interest and occurs in measurement instrumentation, acoustics and other mobile communication contexts.

During the last year many papers in both mathematics and electrical engineering have been concerned with this problem. The first theoretical results on this topic were published by Salem and Zygmund in 1954, but fundamental results are still sparse. Most authors in mobile communications do not take the PAR distribution into consideration. In a more heuristic manner, they propose modifying the multicarrier signal so that the peak value is reduced and the information loss is as low as possible. Some analytical results have been obtained by assuming Gaussian distributions and reducing the observed time instants to the Nyquist set. This strategy is rather complicated and does not apply in practice. Thus a new approach has been pursued, in which the OFDM signal is considered on an oversampled set. An inequality has been derived that allows the peak value to be estimated by a small constant from the peak value on the oversampled set. Hence the PAR distribution of the set, which is obtained by probabilistic methods, is used to estimate the PAR distribution of the OFDM signal itself [1] [2]. The figure shows the PAR distribution of 1024 subcarriers.



PAR distribution of an OFDM signal with 1024 subcarriers

The new technique can be applied to general modulation schemes. It can also be used to design more accurate error models for OFDM systems and even to develop OFDM codes with reduced PARs. A further important application of the peak value estimate is in the well known clipping algorithm, which has been proposed to design multicarrier signals with low PAR under additional constraints. This algorithm is usually implemented using the Fast Fourier Transform (FFT), and the estimate can be used to calculate a good FFT order for the given problem.

This work is supported by the German Ministry of Education, Science, Research and Technology (BMBF) under grant no. 01 BK 611/3.

[1] G. Wunder and H. Boche, "Peak Factor Estimation of Oversampled Trigonometric Series", Berlin, November 1999, Preprint.

[2] H. Boche and G. Wunder, "Analytical Derivation of Crest Factor Distribution of Binary Sequences in Multicarrier Systems", Berlin, November 1999, Preprint.

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Wireless Infrared Communication: An Integrating Sphere Diffuser

A new diffuser for wireless infrared (IR) communication systems is proposed based on a small integrating sphere. It transforms each beam characteristic of the IR transmitter into that of a large-area wide-beam source, which is commonly required for the eye-safe illumination of large IR cells.

The infrared channel is a potential candidate for high-speed indoor communication between portable computers and the domestic wired network. For this application, the light from the IR base station mounted on the ceiling is spread to all mobile terminals in the cell. This is usually done by placing a diffuser in front of the IR transmitter.

The use of an integrating sphere as a diffuser is investigated in this report. The sphere is made of Spectralon®, which is a good Lambertian diffuser material with reflectivity $\rho = 0.99$. Since Spectralon® is a plastic material, the sphere can be manufactured in large numbers. It has a diameter of 10 mm and a central target of 2 mm diameter. The entrance and exit ports have diameters of 1 and 5 mm, respectively (Fig. 1).

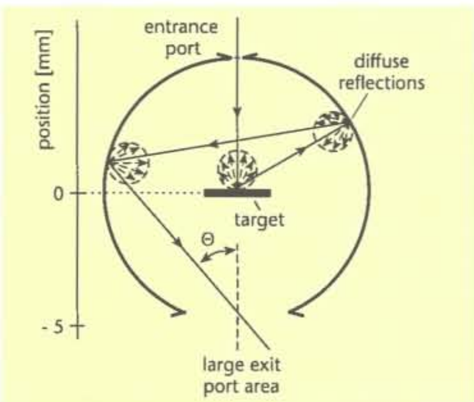

Fig. 1:
Principle of the integrating sphere diffuser

A relatively large port area (6% of the total surface) is used to reduce the insertion loss. The beam characteristic from large exit ports is well known to deviate from the ideal Lambertian profile. For this reason the diffuse light propagation in the sphere was modelled using random walk ray tracing simulations [1]. In the model, the random path of each photon in the sphere is traced. After a large number of trials, statistical data on the insertion loss, the beam profile and the temporal response are obtained. The sphere was also manufactured in Spectralon® and its properties were verified experimentally.

In Fig. 2 the simulated and measured beam profiles from the exit port are compared. They agree very well. Because of the large exit port, the transmitter beam, with a full width at half maximum angle of 104°, is slightly narrower than a Lambertian source. With this diffuser, an area of 20 m^2 can be illuminated 2 m below the ceiling with intensity variations of 6 dB. Due to the large exit port area the diffuser is eye-safe up to 1 W at 900 nm [1].

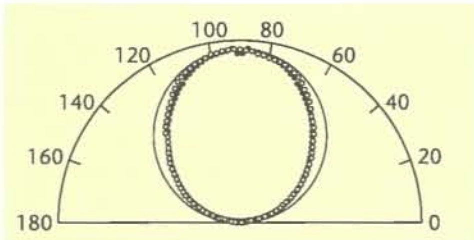

Fig. 2:
Simulated (filled circles) and measured (open circles) beam profile of the diffuser. For comparison, the Lambertian characteristic (solid line) is also shown

The multipath light propagation in the sphere causes a delay spread of the data signals at the receiver, which can be modelled as an equivalent electrical lowpass having the cut-off frequency f_0 [1]. In Fig. 3 the simulated and the measured amplitude response are shown. The electrical insertion loss is 1.2 dB and f_0 is roughly 500 MHz, which is sufficient for data rates up to 622 Mbit/s.

In conclusion, a sphere diffuser for high-speed wireless infrared communication is proposed. The diffuser offers both good efficiency and high bandwidth, and it makes high optical powers possible in wide transmitter beams.

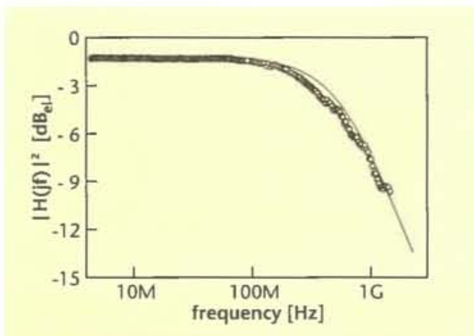

Fig. 3:
Simulated (solid line) and measured (open circles) amplitude response of the diffuser

This work is supported by the German Ministry of Education, Science, Research and Technology (BMBF) under grant number 01 BK 611/3.

[1] V. Pohl, V. Jungnickel, R. Hentges and C. von Helmolt, "Integrating Sphere Diffuser for Wireless Infrared Communication", Proc. IEE Colloquium on Optical Wireless Communications, London, June 1999, pp. 4/1-4/6.

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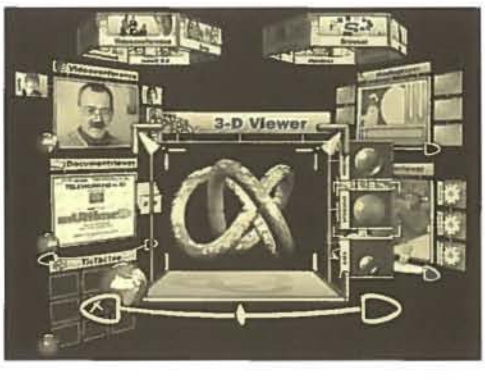
3D User Interfaces and User Interaction for Next Generation Multimedia Desktop Computers

A visual 3D operating system for computer workstations has been developed that supports the three-dimensional presentation of information on autostereoscopic 3D displays. The novel graphic user interface provides a three-dimensional interaction area, with various media objects floating in 3D space. The operating system supports novel forms of human-computer interaction using inputs from various video-based devices for head, gaze and hand tracking (multimodal user interface).

Graphical human-computer interfaces based on windows, icons, and mouse pointers have simplified computer use. However, two-dimensional surfaces are restricted by overlapping windows that inhibit screen visualisation. Three-dimensional displays help visualise the data flow and interplay of programs, e.g. in complex multimedia applications. Spatial structures can be perceived and interpreted more easily. Thus, the third dimension opens up the possibility of providing displays with clearer viewing structures.

An intelligent and interactive 3D human-computer interface has been developed that understands the user's intentions and helps navigate and manage information resources. The computer "watches" the user and anticipates actions, without necessarily being prompted by mouse or keyboard commands. Intelligent software agents acquire data about the user, supervise and interpret actions, organise the interaction area accordingly, and (within certain limits) act autonomously.



Screen shot of the new visual 3D operating system (multitasking with six applications open simultaneously)

The visual 3D operating system supports 3D presentations on autostereoscopic displays. The 2D user interface of current computers becomes a 3D interaction area, with media objects floating in 3D space as illustrated in the figure. The top of the display shows toolboxes with icons for applications or tasks. When the user looks at an icon, the computer displays a confirmation signal. If the user accepts the selection (e.g. by a spoken command), the interface agent starts the application and moves it to the foreground, at the same time minimising and shifting the other objects to the background. Looking at one of the background objects will fetch it back to the foreground. Changing viewing angle by moving the head allows the user to look at sides of the toolboxes that were not visible. The 3D operating system supports telecooperation in 3D, including the presentation of live video images which can be mapped onto arbitrary surfaces (live texture mapping).

The user's head position is sensed by a video-based head tracker. For initialisation, the tracker waits for an eye blink to identify the eye region. The pattern is stored and is used to find the eye positions after head movements. Non-intrusive, precise gaze measurements are made using the cornea-reflex method, in which illumination with infrared light-emitting diodes produces a highlight on the cornea. The position of the pupil in relation to the highlight depends on the gaze direction, and is used to estimate the user's current gaze point.

Future work includes the integration of other interaction modalities, such as video-based interaction using hand gestures, into the prototype system. The goal is to ease computer operation by improving the computer's perceptual and intellectual capabilities.

This work is supported by the German Ministry of Education, Science, Research and Technology (BMBF) under grant number 01 BK 802.

[1] S. Pastoor, J. Liu and S. Renault, "An experimental multimedia system allowing 3-D visualisation and eye-controlled interaction without user-worn devices", IEEE Transactions on Multimedia, Vol. 1, No. 1, pp. 41-52, 1999.

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3D Teleworking – Displays and User Interaction

A new autostereoscopic 3D display based on lenticular-screen 3D technology has been developed for teleworking in 3D. The display is mounted an a movable platform allowing rotation around the vertical axis and movement towards or away from the user. Using a video head tracker, the display orients itself to the user's face and maintains a constant viewing distance (face-to-face 3D display). In a telecooperation environment, the HHI visual 3D operating system (VOS) supports joint editing of 2D and 3D objects as well as videoconferencing for up to four teleworkers.

A prototype system for teleworking in 3D has recently been developed, and was presented to the public at the International Broadcasting Exhibition IFA 99 in Berlin. The system comprises an autostereoscopic 3D display, a visual 3D operating system, a camera that senses head position and motion, and a system that determines the user's gaze direction. The display represents images produced directly by the computer's operating system or by cameras and other video sources in videoconferencing. The video signals are projected onto virtual 3D screens integrated into the 3D display, using dynamic texture mapping techniques.

Simple movements of the user's head are detected by the head tracker, which can then make occluded objects become visible (the motion-parallax effect). Simultaneously, the gaze tracker determines the user's point of fixation, which may for example result in a partially hidden document being pulled closer to the user and displaying its contents if the user just looks at it. Likewise, interactive icons and virtual buttons may be selected by the user's gaze (eye mouse). In a simulated teleconference, any modification of a document or 3D object initiated by one of the users (e.g. changes of lighting, switching to a wire-frame presentation, or modification of surface colours) immediately take place on all connected workstations.

The autostereoscopic 3D display uses direction multiplexing, so that the two different perspectives are visible only from a certain range of viewing positions. When the user's eyes are in the stereo zone, the views are fused to create an illusion of 3D space. The display requires a head tracking mechanism to optically address the user's eyes as the head position varies. The face-to-face 3D display is a monitor that follows the user's face movements, providing an image over more than 120 degrees and maintaining a constant distance of 72 cm from the user (see figure). The prototype screen measures 15.1 in and has 1024x768 pixel resolution, giving a stereo resolution of 512x768 pixels.

A regular array of thin vertical cylindrical lenses selectively addresses the user's eyes. The LCD screen behind this lenticular plate displays the left and right data sources simultaneously in adjacent pixel columns. Odd columns address the right eye, even ones the left. Each lens covers a pair of left/right pixel columns. The lens pitch and the air gap between the lenticular plate and the LCD determine the stereo zone location. Colour quality and resolution are high because of colour stereo multiplexing (which means that the primary colour components forming an RGB colour pixel are projected separately).

The autostereoscopic 3D display developed for teleworking in 3D. It orients itself to the user's eyes for a face-to-face 3D display

The video head and gaze tracking techniques have been implemented on both the Unix and Windows NT platforms.

This work is supported by the German Ministry of Education, Science, Research and Technology (BMBF) under grant number 01 BK 802.

[1] S. Pastoor, "3-D displays and video trackers ease computer operation", Photonics Tech Briefs, Europhotonics, 10/11 1999.

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Robust PC Software Head Tracker for Multimedia Applications

This paper describes a software solution for a real-time head tracker integrated into an interactive multimedia 3D workstation. The user's eyes are detected and tracked in video images supplied from a video camera. The current 3D position of the user's head is calculated for use in multimedia applications.

The 3D position of the user's head in head-shoulder video images can be localised very precisely in real time on a general purpose PC without any special hardware. This information is used to control an autostereoscopic 3D display as well as human computer interactions in multimedia applications. This software guarantees robust and fast tracking.

In the initialisation phase we detect the user's blinking to find the eyes in the video images (e.g. figure), as blinking is a natural and involuntary human action that keeps the eye moist. In order to detect eye blinking, the motion information from successive images is analysed. The three regions in the images with the most motion are initially selected. The selected regions must comply with certain rules to be sure that they include the eyes. The motion information in the two regions including the eyes must be more significant than in the third one. Additionally, the two eye regions must have similar motion information and satisfy the geometrical relationships appropriate for the eyes. Based on the detected eye regions, three eye pattern pairs (EPPs), appropriate to three user distance zones from the video camera, are created and stored. These are used in the following tracking procedure as reference patterns.

Detected eye regions in a head-shoulder video image

Detection of the eyes in the following video image sequences is based on a block matching technique. The distance between the user and the camera is detected, and the current EPP will be replaced by another if the user crosses from one distance zone to the next. Also, the detected eye regions in the current image will be taken into account in the matching process, to compensate for the variations in size and luminance. A dynamic search area is defined to speed up the tracking procedure. The search area in an image normally surrounds the eye positions in the previous image, but if the eyes are lost, the whole image is selected as the search area. After the 2D eye positions are found, the 3D head position is calculated, based on knowledge of the camera specification and of the user's inter-ocular distance. This algorithm is able to track the head at 50 frames per second on a Pentium II (450 MHz) PC without special image processing hardware.

The head tracker is integrated into an experimental 3D multimedia workstation [1] that also includes an autostereoscopic 3D display, an interactive 3D GUI and a gaze-tracking system. The display control unit uses the estimated head position to ensure that the display moves its stereo zone to the current user's eye positions. The 3D GUI exploits the head position to show the user a correct perspective of a 3D view. The head position is also used to control the gaze camera, which is mounted on a pan/tilt unit and which captures the user's eyes in high resolution to track the user's gaze direction. Users can select an object on the display simply by looking at it, and can change its perspective by moving their head.

This work is supported by the German Ministry of Education, Science, Research and Technology (BMBF) under grant number 01 BK 802.

[1] S. Pastoor, J. Liu and S. Renault, "An experimental multimedia system allowing 3D visualisation and eye-controlled interaction without user-worn devices", IEEE Trans. on Multimedia, vol. 1, no. 1, March 1999, pp. 41–52.

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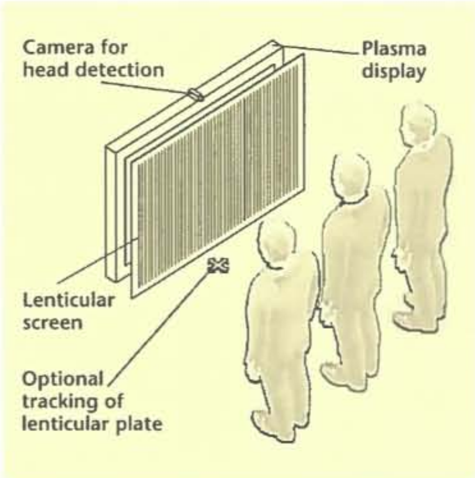
Wide-Screen 3D Multi-User Display

A 42 inch 16:9 autostereoscopic display has been developed by combining a plasma display of 852x480 pixels with a lenticular plate. With the stationary lenticular plate, three viewers, sitting in restricted viewing areas, can simultaneously see spatial images. If only one viewer uses the monitor, the viewer is allowed to move in front of the screen within an area of $^1/_2$ m x $^1/_2$ m, but the lenticular plate, controlled by a video-based head tracking system, has to be shifted electromechanically.

The benefit of binocular vision in recognising spatial structures and virtual objects must be made use of in future information and communication systems. Stereoscopic displays in simulators, control stations, computer workstations, communication monitors, medicine, multimedia and game machines will be important for successful interaction. In our present project, four autostereoscopic projection systems and flat monitors, all working without special eye glasses, are being researched.

Our most universal 3D monitor of 852 x 480 pixels is a combination of a 42 inch plasma display in 16:9 format and a glass plate with a lenticular structure in front of the display. In order to present to the two eyes the two rastered two-dimensional images from two different viewpoints, this flat arrangement of many cylindrical lenses directs the light from all the pixels of both raster images selectively into restricted stereo viewing zones for the left and right eyes. Within these viewing areas there is proper spatial imaging, and at the same distance from the screen, adjacent viewing zones of gradually declining quality are available for additional viewers. The number and area of the viewing zones is appropriate for up to three viewers, due to the large pixel columns of the plasma structure and the excellent optical quality of the lenticular screen. A typical application of this autostereoscopic multi-user monitor is in simulators with seats and head rests.

A conventional raster stereo image in a landscape-format display with a lenticular plate presents the three colours of the left and right channel in different viewing positions due to the horizontally aligned colour pixels. This mismatch is avoided by multiplexing the addressing of the colour pixels. The three colours of the image point for the left eye must consist of the triple G-R-B and those for the right eye of the triple R-B-G. With this method, both eyes see the complete left and right full-colour image strips through three adjacent lenses. On such a multiplexed panel, the triple of two adjacent strips of colour subpixels of the two raster stereo images are located behind three lenticulars. As a result, the number of lenticulars of the screen must be tripled, and the required precision of the lenticular structure increases considerably.



Autostereoscopic plasma monitor with lenticular screen

An additional feature for single users is also implemented in this 3D monitor. To overcome the restrictions of the small viewing areas, a video-based head detection system indicates the position of the viewer in front of the screen. This data is processed and used to drive four electro-mechanical control devices. These devices shift the lenticular plate when the viewer moves, thus moving the viewing zones. Correct views, corresponding to the viewer's position, may be created by tracked cameras or by rendered real-time computer graphics, facilitating natural look-around capabilities.

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3D Display with Accommodation Technology

A novel autostereoscopic 3D display allows for the natural interaction of eye convergence and accommodation when looking at objects at different distances. This display will be particularly useful in mixed-reality applications. As opposed to state-of-the-art stereoscopic displays, users can interact with the floating 3D image of a virtual object using their hands or a real instrument (manipulator), seeing both the real and virtual objects in full focus. This display is considered to be a key to the implementation of novel forms of human-computer interaction.

Existing 3D displays have an inherent shortcoming: the user must focus on a fixed viewing distance (the screen distance), although the virtual objects may stereoscopically appear close to the eyes or far behind the screen. By contrast, in natural viewing conditions the accommodation distance changes with the distance of the object observed (convergence distance of the lines-of-sight). This mismatch of accommodation and convergence is a major source of visual fatigue experienced with current 3D displays.

The fixed viewing distance of a 3D display causes especially severe problems in mixed-reality applications, in which users see both their natural environment and virtual (computer-generated) stereo objects simultaneously. If the user looks at a real object (e.g. the pencil shown in the left image of Fig. 1), the eyes automatically focus on this object, producing a blurred retinal image of the virtual scenery shown on the 3D display. On the other hand, if the user looks at a virtual object, his or her eyes will accommodate at the display distance, shifting the real object out of focus (as in the right image of Fig. 1). The overall effect is that even if the virtual object appears at the same stereoscopic distance as the real object, either the real object or the virtual object may produce a blurred retinal image. Hence, any natural interaction is substantially hindered.

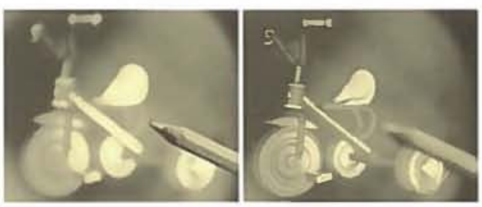

Fig. 1: **With conventional 3D displays the user must focus at the screen distance to see the virtual object in full focus. Hence the real object (the pencil) produces a blurred retinal image**

In order to make 3D display viewing more comfortable and to support mixed-reality applications, we propose the 3D display concept shown in Fig. 2 [1].

Note that the stereo image is not projected onto a physical display screen at a static location – instead, the display provides a movable image plane, whose position depends on the focal settings of the projection unit. From the user's point of view, the displayed stereo objects may float in front of or behind the large Fresnel-type field lens (floating aerial images). The location of the image plane may be controlled by adjustments of the projection optics (focus), so that the aerial image appears at a distance corresponding to the stereoscopic distance of the virtual object the user is currently looking at.

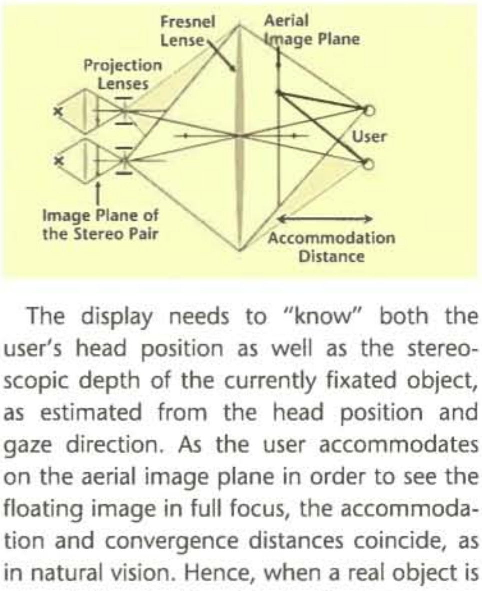

Fig. 2: **Top view of the new display concept. The user accommodates on the aerial image plane and perceives a floating 3D object. The Fresnel lens projects the exit pupils of the stereo projector to the left and right eyes, respectively (field-lens principle)**

The display needs to "know" both the user's head position as well as the stereoscopic depth of the currently fixated object, as estimated from the head position and gaze direction. As the user accommodates on the aerial image plane in order to see the floating image in full focus, the accommodation and convergence distances coincide, as in natural vision. Hence, when a real object is placed close to the virtual object, both objects will appear in full focus (Fig. 3), allowing comfortable mixed-reality interactions.

Fig. 3: **With the novel 3D display the user may see both the virtual object and the real object in full focus**

This work is supported by the German Ministry of Education, Science, Research and Technology (BMBF) under grant number 01 BK 802.

[1] G. Boerger and S. Pastoor, "Autostereoscopic display", patent no. DE 195 37 499, 1997.

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Trinocular Depth Estimation in Images

Three cameras in a particular asymmetrical set-up are used in a 3D interactive system to obtain the depth information from a videoconferencing scene. Following stereo image analysis, the scene is decomposed into a variable number of depth layers. Applications include synthesising 3D images for enhanced telepresence, allowing the user to "look around" natural scenes, and improving viewing comfort with 3D displays by giving stereo images a natural depth of focus.

At HHI a hybrid image analysis approach is being developed that combines the results from 2D colour image analysis and 3D stereo image analysis in a novel cooperative procedure to determine the in-depth position of the objects in a scene. Our approach uses three cameras arranged, for example, around a display for video communications. Two cameras are placed one above the other to form a stereo unit with a rather short baseline. The third camera is placed at a larger distance (e.g. on the other side of the display), thus providing a large stereo baseline. This asymmetrical arrangement has the advantage that a coarse disparity map is easily estimated using the two closer cameras, whereas more accurate depth estimates are obtained with the large baseline camera pair.

The whole procedure is illustrated in Fig. 1. First, one of the 2D images is segmented into regions by exploiting both the colour and the edge information. Independently, a correspondence analysis is performed on the short baseline camera pair. The disparity map is segmented into regions using the same segmentation technique as used for the 2D image cues. Because of reflection and shading on the object surfaces as well as perspective differences in the camera views, the two different segmentation techniques will give different segmentation results. Hence, decisions on the true region contours are required. This process is governed by a set of rules that extract the most reliable results from the two segmentation techniques. The results are refined further by using the disparity information from the large-baseline camera pair. At each stage of this process, the disparity estimation and the detection of the half-occluded regions are guided by the segmentation results from the previous stage.

Figure 2 shows a layered representation of a scene with artificial depth of focus, which improves viewing comfort when the scene is shown on a 3D display.

This work is supported by the German Ministry of Education, Science, Research and Technology under grant number 01 BK 802.

[1] Liu, Przewozny and Pastoor, "Layered representation of scenes based on multiview image analysis", to be published in IEEE Trans. on CSVT, June 2000.

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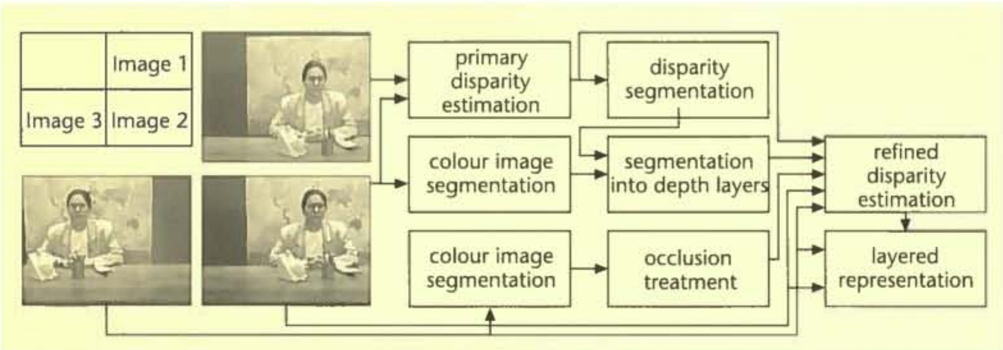


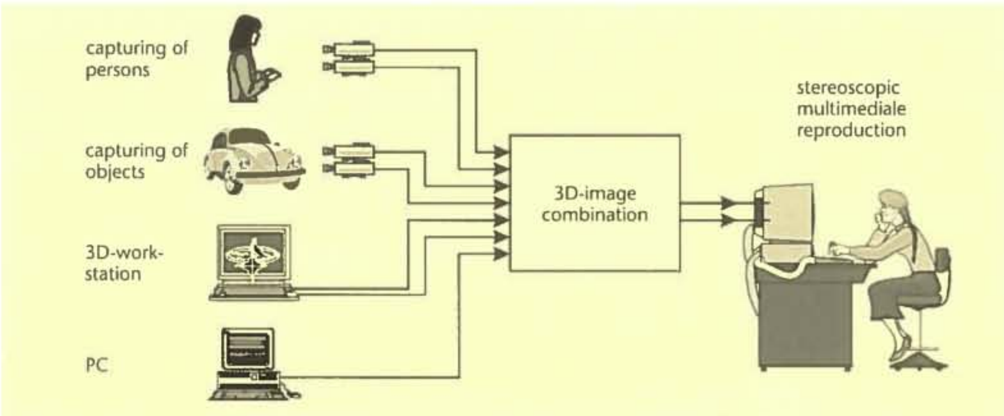
Fig. 1:
Structure of the trinocular image analysis and synthesis system

Fig. 2:
The current attention of the user is assumed to be on the person in the middle layer. The background and foreground layers are blurred, so that they fade from the user's attention

Guidelines for the Composition of 2D and 3D Images on 3D Displays

Future multimedia desktop applications will consist of 3D and 2D presentations on the same screen. Since these images differ in various parameters, we wanted to establish some guidelines for combining different image sources. The results show that the boundary between two stereoscopic images should be realised in the background, and the join should be either seamless or covered by a bar. If monoscopic and stereoscopic images must be displayed together, they should be joined in or near the background of the stereoscopic image.

In future multimedia desktop applications, different images – monoscopic as well as stereoscopic – from different sources will be combined on the same screen, as illustrated in the figure. Apart from their dimensionality, these images may differ in several other basic parameters, such as depth, brightness or perspective. The problem of combining these different images in a perceptually comfortable and undistorted manner thus arises.



Combination of 3D and 2D images

As first pilot trials showed, the boundary between distinct images must be designed in a visually perfect manner, as otherwise different depth values or the truncation of parts of objects can cause eyestrain. Consequently, we carried out a further human factors study aimed at analysing and comparing different arrangements of stereoscopic and monoscopic images, using images with various depth and brightness values and with different image separations.

A graphics computer was used to generate the appropriate stimulus material. For image presentation we used a 10.4" autostereoscopic field lens display that had been developed at HHI as a prototype. Due to technical constraints, the stimulus set was limited to still images showing a realistic scene – a model of a motorcycle.

Thirty distinct image combinations, each consisting of two images, were presented to the test subjects. The most important results can be summarised as follows:

- If two stereoscopic images must be combined, a seamless (i.e. unobtrusive) boundary between them proved to be the best solution.
- If an obvious boundary between adjacent images cannot be avoided, a thick line or bar covering it proved to be better than frames.
- Seamless arrangements of 3D images should be realised by joining them in or near their backgrounds.
- If monoscopic and stereoscopic images must be combined, the monoscopic image should be presented so it lies in the background of the stereoscopic image.
- If image separation is realised using frames, the depth location of a monoscopic image in relation to a 3D image proved to be insignificant. This is valid for 2D text as well, although a tendency was found to prefer 2D text in the screen plane when combining it with a 3D image.

Overall, 3D image combinations were evaluated as being more attractive and more natural. They induced a higher degree of telepresence and were more appealing than 2D image combinations. This is also valid to some extent for 2D and 3D combinations joined in the background.

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Virtual Presence for Telework Applications

Informal communication within enterprises not only improves job satisfaction but also increases work efficiency. It also has the potential to reduce the social isolation of teleworkers. Hence telework and telecooperation systems must be able to support this type of communication. This project therefore aims to develop a communication platform that supports informal communication, in the context of telework, by employing virtual presence in virtual environments.

Telework and telecooperation are becoming more and more important. However, there are some reservations about telework because of fears about the social isolation of the teleworkers and fears about lack of control by management. To a certain extent this is due to the fact that the natural communication behaviour common in enterprises is restricted by the conditions of telework. This applies in particular to informal communication. Studies have shown that informal communication not only improves work satisfaction but also increases work efficiency.

Considering those facts, a project was started to develop and test a communication platform that supports informal communication in the context of telework. In addition to common features for computer supported cooperative work (CSCW), this platform will come with a special informal communication module enabling – among other things – the various phases of communication that people know from face-to-face encounters, including the exploration phase, the negotiation phase, and the actual communication phase.

Our hypothesis is that virtual presence provided by virtual environments is particularly suitable for supporting those phases of communication, since it allows the intuitive recognition of communication signals, and the room metaphor supports actions such as virtually approaching other people. In addition, virtual environments seem to be a good compromise between the teleworkers' demands for telepresence on the one hand and protection of privacy on the other.

During the first year of the project, exploratory user trials have been carried out, including the testing, among other systems, of some commercially available virtual environment software (Fig 1).

As a major result of the studies carried out so far, it turns out that automatic measurement of the users' willingness to communicate is essential. Hence, as a first step in this direction, a software component ("Presence Monitor") was developed that analyses the activity in video images from a workplace camera to decide whether a team member is present at his/her workplace or not. In a test version of an informal communication module, the result of the Presence Monitor component is displayed as a presence icon (Fig. 2).

Fig. 1:
A virtual office environment (System Roomancer)

Fig. 2:
Presence icons (on the right side) indicate the current availability of workgroup members

The work is supported by the Federal Ministry of Economics and Technology of the Federal Republic of Germany under grant number 01 MT 901/7.

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Next Generation Multimedia Search Engines with User Adaptation

The retrieval of digital images based on image content information has been the subject of considerable research efforts in recent years. However, the proposed approaches have mostly ignored human perception and behaviour, and therefore have many drawbacks. The main goal of a project at HHI is to develop new concepts in image retrieval systems for searching, visualisation and content description that are based on human perception and behaviour.

Retrieval of digital images based on image content information rather than text descriptions has been the subject of considerable research efforts in recent years. The commonest approach has been to attach real-valued attributes to the visual data, each attribute being the parameter of some content descriptor, e.g. colour distribution, texture or shape. Together with a distance function, these attributes define a measure of image similarity. Some examples are QBIC and Photobook. But the proposed approaches have largely ignored human perception and behaviour, and so have considerable disadvantages.

Therefore the main goal of a project carried out at HHI is to develop new concepts for searching, visualisation and content description in image retrieval systems that are properly based on the human perception and behaviour.

Intuitive visualisation of the "image space"

One topic is to explore how humans perceive image content and how to integrate such a "human model" into the image retrieval system. Therefore a study of human perception of images at a psychophysical level is crucial. The results will contain a collection of perception-based descriptors and the corresponding similarity measures.

Another topic is the perception-based visualisation of the "image space". A retrieval system should return images that are displayed not only in order of decreasing similarity from the query, but also according to their mutual similarities in a two or three dimensional way. With such a view the user can see not only the relations between images, but can also see larger portions of the database at a glance and form a global mental model of what is in it (see Fig.).

One important aspect of image search systems is the active role played by the user. By modelling the users and learning from them in the search process, image search systems can better adapt to the users' subjectivity. In this way, we can adjust the search system to the fact that the perception of the content varies between individuals and over time. User interaction with the system includes online queries and feedback to the queries. Iterated navigation and query refinement is an essential key in finding images, since our emphasis is on "the human in the loop".

A further topic is to close the gap between "low level" descriptors, such as colour, texture and shape, and the semantic descriptions. At present, image search engines are not able to recognise objects described semantically in general situations. The main problem is that semantic objects cannot be characterised by a single image parameter such as colour. Therefore a more complex combination of several image parameters, depending on the semantic meanings of the objects, has to be used. For this purpose preferred objects are collected either by user interaction or more automatically by monitoring user behaviour. Based on these collections of templates, algorithms for the detection, localisation and segmentation of preferred objects in image data bases are being investigated.

The results of these investigations are being realised in various demonstrators.

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HHI Activities under the MPEG-7 Framework

MPEG-7, the „Multimedia Content Description Interface", is a new standard presently being defined by the Moving Pictures Experts Group (MPEG). This contribution gives a short overview of MPEG-7 and its applications, as well as the contributions that HHI has made to the definition of the standard.

The amount of multimedia content in worldwide information networks is forever increasing. To make efficient use of these sources, new description mechanisms must be defined. These can be used for simplified and more efficient procedures during activities such as:

• Content-based searching for multimedia sources in archives, databases, broadcast channels and the Internet;

• The production, annotation, editing and manipulation of multimedia content;

• The acquisition and presentation of the content.

In order to achieve high flexibility in useful descriptions for many different applications, the basic structure of an MPEG-7 description includes:

• Descriptors (D), which describe simple features such as the colours of images, motion within video, or the harmonic properties of music;

• Description Schemes (DS), which are structures built from multiple Descriptors or other subordinate DSs;

• A Description Definition Language (DDL), which allows the specification of descriptions and structures that are not normatively defined within the standard.

HHI has actively participated in the definition of MPEG-7, its main focus being on Descriptors for visual signals (images, video, graphics) and low-level DSs. The following technical proposals were submitted by HHI:

• A framework for the description of colour, consisting of a specification of colour space, colour quantisation and colour representation in terms of histograms or dominant-colour clusters;

• A visual texture description based on wavelet frequency analysis and representations by histograms and statistical moments;

• A description of the shapes or contours of objects by a scalable wavelet representation combined with primitive properties of the object's bounding box;

• A description of object or background motion based on parametric motion models;

• A DS which combines basic feature Descriptors to characterise the spatio-temporal behaviour of regions within visual scenes;

• Methods for the specification of basic interfaces with databases that include the content as well as the description.

Over 400 proposals were evaluated by the MPEG experts. From these, the colour description framework and the parametric motion description proposed by HHI were accepted as elements of the so-called MPEG-7 eXperimentation Model (XM), which is a preliminary version of the standard [1]. Elements from other HHI proposals were either combined with similar ones or are being further investigated in experiments conducted by MPEG.

Visual similarity retrieval based on colour and texture features

We have developed, as an example application for MPEG-7, an Image Search Engine (ISE) that can retrieve similar images and videos from large databases on the basis of their visual properties. The figure shows the retrieval results that were obtained by taking the search image (left) as an example query, based on colour and texture features. The images on the right were found to be the most similar ones, based on the MPEG-7 feature description.

This work was supported by the German Federal Ministry of Education, Research, Science and Technology under grant number 01 BN 702.

[1] S. Jeannin (ed.), "MPEG-7 Visual part of eXperimentation Model Version 3.0", Doc. No. N2931, Melbourne, Australia, October 1999.

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2D and 3D Contour Description using Wavelets

In the upcoming MPEG-7 standard, image and video material will be described by Descriptors and Description Schemes. Among the most important image features are contours or shapes of the arbitrarily shaped objects in 2D images and of the surfaces of objects in 3D scenes. We have developed a compact contour description using wavelet analysis that allows a hierarchical representation and coding down to a very small number of bits.

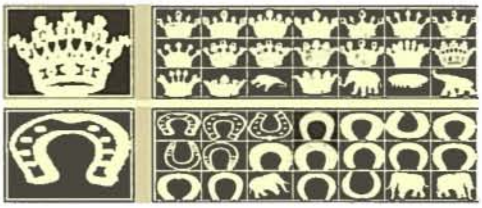
The MPEG-7 description requires the representation of visual content by a much smaller amount of data than in common coding techniques, in order to allow fast similarity-based retrieval of images from huge databases. The challenge is to find the best compromise between a small descriptor size and high retrieval rate of similar contours. This can be achieved by a hierarchical representation, which enables a coarse pre-selection of a subset of items based on a raw-level description, followed by a highly accurate refinement based on a more complex similarity comparison.

We have developed a description of image contours that uses a hierarchical wavelet-based transform of shape features [1]. A contour is represented by the wavelet transform of its magnitude values in polar coordinates, which contains most of the information. The phase values may be neglected in the wavelet description for the purpose of similarity comparison, which reduces the descriptor size.

Similarity-based retrieval of contours

Even though the compression of the contour information achieved by the wavelet transform is considerable, this representation is still not compact enough for fast searches in very large databases. Hence, it is useful to set one global parameter for each contour at the top of the Descriptor hierarchy. This parameter represents the ratio of the principal axes of the "bounding box" of the object, which are the width and length of the smallest surrounding rectangle. This can be used to classify the contours in terms of their form, i.e. whether a contour is needle-like, elliptical or circular. This global form parameter ranges from 0 to 1, and is quantised into 16 discrete values. If a reference contour from an image is compared to the contours in a database, only those contours are considered whose form parameter is within two steps of that of the reference contour.

The fine comparison stage considers the wavelet coefficients of the reference and database contours. The complexity of this comparison can be adjusted by choosing the number of coefficients being compared. A minimum of 16 values is required, but if additional wavelet coefficients are used, more exact matches are possible. The values of the contours are compared in a way that guarantees translation, scale and rotation invariance. The square error between the wavelet representations is taken to be the distance measure and thus defines the similarity between the contours being compared. The contour description was tested in the MPEG-7 core experiments and achieved a retrieval rate of 84% [2]. The most compact descriptor size is 80 bits per shape. The figure shows examples from a similarity-based retrieval using the MPEG-7 contour database.



The wavelet-based contour descriptor was also applied for similarity-based retrieval of projection images of 3D objects, which allow a more efficient description and search than using 3D features. We generated characteristic views from 3D objects, so that the description and similarity search could be based on 2D contour description. With this mixed 2D/3D approach it is possible to identify 3D objects from 2D views.

This work was supported by the Deutsche Forschungsgemeinschaft under grant number OH 50/5-1.

[1] K. Müller, J.-R. Ohm, "Contour description using wavelets", WIAMIS '99, Berlin, May 1999, pp. 77-80.

[2] ISO/IEC JTC1/SC29/WG11, "Results on MPEG-7 core experiment shape-1", Document No. M4740, July 1999, Vancouver.

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NEMESIS – Advanced Video Processing Tools for Professional Post-Production

The European ESPRIT project NEMESIS project aims to develop a set of products for professional digital post-production applications. These products will be implemented as plugins for Adobe "After Effects", and will allow 2D and 3D visual data to be accessed, displayed, manipulated, altered and stored on the basis of its content.

NEMESIS proposes to develop and integrate semi-automatic, interactive analysis/synthesis tools to ease day-to-day post-production work, to provide new functionalities, to save time and to reduce production costs. The package will integrate the functionalities: advanced spatio-temporal segmentation (as an alternative to existing keying techniques), layering, interactive off-line camera calibration, 3D/2D registration, modification of camera framing and angle of view, and static image segmentation. The consortium consists of a coordinator (Thomson-CSF Optronique), an end user (Mikros Image), and three academic partners (HHI, ICS-FORTH, INRIA/IRISA).

Individual foreground objects and background panorama images can be extracted using NEMESIS. Camera parameters and the 3D trajectories of the extracted objects can also be estimated. For these purposes, NEMESIS offers the following tools:

Rotoscopy: Objects defined by their contours can be tracked through the scene. This tool is based on the computing engine of IMANA from HHI (see "IMANA – An Interactive System for Video Segmentation in TV Post-Production" on the following page in this annual report). At each frame the user may intervene and correct errors. Rotoscopy can deliver the object contour, the binary object mask or an alpha mask, ready for soft keying.

Static Segmentation: Algorithms from HHI and ICS-FORTH provide means of initialising an object for use with rotoscopy, and also assist the user to make manual corrections of the rotoscopy results.

Mosaicing: Methods developed by IRISA estimate a panorama background image from an image sequence. The background image is used by tools for re-framing and zoom modifications.

Texture Filling: Texture filling algorithms are being developed by ICS-FORTH to fill holes in background images computed by mosaicing.

3D/2D Tracking and Interactive Calibration: To compute the 3D translation and rotation parameters of an object, a 3D model can be registered to an object and tracked through the sequence. Camera parameters can also be estimated. This tool was developed by INRIA.

During the first year of the project, specifications for the integration of the algorithms on the desired platform were developed. HHI did a full port from the UNIX-based IMANA system to the NT-based plugin for Adobe "After Effects". Some modules were also re-engineered to provide more general functionality.

Furthermore, specifications for the interfaces with Static Segmentation to assist the user during manual corrections, and with Mosaicing to support rotoscopy with background information for sequences with a non-static background, were defined in co-operation with the other partners.

In addition, HHI contributed various inputs to the MPEG-4 Studio Profile on behalf of NEMESIS.

This work is supported by the ESPRIT programme of the EC under grant number 28265.

[1] J. Figue, "European NEMESIS project: Multimedia audiovisual post-production tools and services", Proc. of WIAMIS '97, Louvain-la-Neuve, Belgium, June 1997.

[2] J. Figue, P. Kauff, B. Maujean, H. Nicolas and J.-M. Vezien, "On the use of a MPEG-4 studio profile for professional post-production", MPEG-4 Doc. 98/4095, Atlantic City, October 1998.

[3] S. Kruse and R. Schäfer, "Advanced processing tools for multimedia production", Conference of International Broadcasting Convention (IBC), Amsterdam, September 1999, pp. 471-476.

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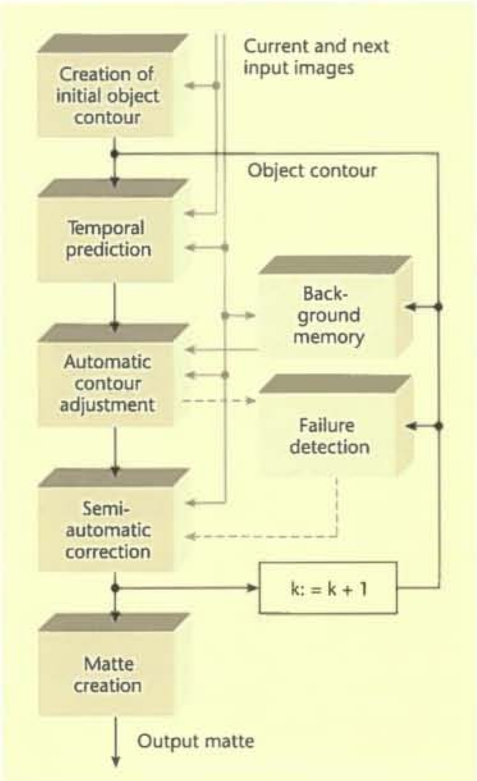
IMANA – An Interactive System for Video Segmentation in TV Post-Production

The fast development of the multimedia market has created a strong demand for post-processed video data. Existing solutions for creating video content still lack automated analysis tools and require long and tedious human intervention to create segmentation masks. Hence there is a need for more advanced analysis tools to simplify production and reduce costs. This contribution reports on an HHI project dedicated to the development of such a tool.

In recent years the task of generating segmentation data from conventional video sequences has become of increasing importance in video post processing, especially due to a growing demand for special effects. Although much effort has been spent on developing automatic analysis tools, automatic image segmentation techniques are still faulty, particularly if applied to general video material. Since it cannot be expected that this situation will change substantially in the near future, semi-automatic segmentation systems are a feasible compromise that may offer significant reductions of production costs.



Outline of IMANA

At HHI such a segmentation system has been developed. This system is called IMANA [1], which stands for "IMage ANAlysing". The figure shows that the system is built basically around a contour tracking kernel, i.e. it tries to follow the contour of a video object over a sequence of consecutive image frames.

The system contains two different tool boxes: still image segmentation tools and temporal segmentation tools. The first tool set is to assist the user during the initialisation of the object contours and the correction of the segmentation results, whereas the second set provides mechanisms for automatically generating segmentation results. Based on these tool sets, a normal segmentation job starts by manually creating a coarse segmentation of the desired video object using the computer mouse. The user can then choose between different tools from the still image segmentation tool box to refine this segmentation. The result of this refinement is then propagated through the image sequence using appropriate tools from the temporal segmentation toolbox. In a final processing step, grey-scale alpha mattes are generated using a matte generation tool. These mattes, which are subsequently used in video mixers for the composition, are the final product of IMANA.

During the tracking process the user may always intervene to switch between tools, to change parameter values, or to correct results manually. In order to simplify the supervision of the process, the user is also supported by a failure detection system that examines the segmentation results to catch error conditions automatically. This eases the supervision of the segmentation process, hence further reducing the production costs.

This work is supported by the German Ministry of Education, Science, Research and Technology (BMBF) under grant number BN 701.

[1] S. Kruse and R. Schäfer, "Advanced processing tools for multimedia production", Intern. Broadcasting Convention (IBC), Sept. 1999, Amsterdam, pp. 471-476.

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VIRTUE – The Step Towards Immersive Tele-Presence in Virtual Video Conference Systems

In the context of the European 5th framework program IST, the project VIRTUE will develop the innovative technology necessary to produce a convincing impression of presence in a semi-immersive teleconferencing system. HHI is a partner of VIRTUE, together with British Telecom, Sony, Harriott Watt University and TU Delft, and is responsible for the real time platform.

VIRTUE will integrate and demonstrate a tele-presence system incorporating many new and innovative techniques. It will investigate the human factors involved in maximising the effectiveness and realism of telepresence, and will use them to drive the design of the system.

VIRTUE aims to advance the state of the art in a number of its component discipline areas, either by proposing novel paradigms, approaches and algorithms, or by pushing forward the frontiers of the current approaches to solve real world problems. It will provide efficient and practical solutions to the critical issues for which no current feasible approaches are available. In detail, the technical approaches are as follows.

Realistic wide view synthesis for dynamic scenes: For a person to appear real and live inside a display, a fast rendering of the moving person's head and upper body from unseen viewpoints is required. This can be achieved without constructing a full 3D model. Instead, the information provided by multiple cameras can be exploited to synthesise new views for a range of viewpoints of the other participants. This will be further combined with novel strategies to combat occlusion in the scene, which is typically created by gestures such as waving a hand in front of one's body.

Object-based segmentation and motion tracking: Robust real-time spatio-temporal object segmentation and motion analysis techniques are to be investigated for object segmentation with an arbitrary office background, using motion-based tracking of different parts of the body. Object-based segmentation will be combined with disparity estimation to refine the segmentation and depth analysis results.

Flexible camera setup: An important aspect of VIRTUE is the independence of the system from the camera and display configuration. To allow a flexible multi-camera set up, registration of camera images is required. Techniques that employ two-view and three-view geometrical constraints will be most important.

Multiple Sensor Fusion: It is necessary to produce an efficient representation of the reflectance and depth information extracted from multiple camera views. This will be suitable for compression and transmission through the systems layer protocol, and also for deterministic rendering for arbitrary angles of view at the receiver.

An artist's impression of a future multi-party video conferencing system with tele-presence illusion

An advanced real-time demonstration system will be designed and constructed aimed at a 3-way tele-presence video conferencing system supporting life-sized upper body video images in a shared virtual environment. The main objectives of the demonstrator are:

- 3D analysis and rendering at full video resolution with frame rates of 25 Hz and above
- Seamless merging of real desks into the virtual desk on the display
- Natural communication environment supporting eye-to-eye contact, spatial awareness, directed body language and motion parallax
- Integration of all participants into the same virtual table environment

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Immersive Television – The Future of Home Entertainment

Being present at a live event is undeniably the most exciting way to experience any entertainment. It is the mission of immersive television to bring this experience to the consumer at home. Apart from conventional audio and video broadcasting, it will incorporate other sensory devices such as motion platforms and olfactory generators, and it will also make use of advanced audio-visual features such as widescreen presentation of panoramic views or "magic carpet rides" using head mounted systems. The ultimate goal is to provide a future experiential and sensory home entertainment that will become as commonplace as the video recorder is today.

Most previous research on immersion has been concentrated in the domain of virtual reality, which is well suited for training, computer-aided design and games.

As a broadcast entertainment medium, however, virtual reality has severe limitations. The quality of computer-generated imagery will be inadequate, for many years yet, to convince a user that he or she is actually viewing real-world scenes. In addition, there is no mechanism for capturing large-scale live events and rendering them in real time. Finally, virtual reality is a highly interactive technology requiring individual processors and wide-band interactive networks.

To overcome these restrictions, the British Independent Television Commission (ITC) has proposed a concept of a new broadcast medium that brings together a host of leading-edge signal processing, media and display technologies to provide unique and exciting immersive entertainment at home.

In this concept it is envisaged to capture, encode and broadcast wide-angle, high-resolution views of live events combined with multi-channel audio, and to display these events in a way that accounts for the head-motion parallax of the viewers. It may also incorporate optional motion seating, olfactory generation (smell), or even temperature control.

The most significant feature, however, is that it targets an one-way distribution service. This means that the same signal can be sent to millions of viewers without the broadcasters having to handle costly interactive networks and servers.

As part of its research, the ITC has commissioned the development of a first experimental platform for immersive television. To make it feasible, the key assumption of this approach is that the viewer's body remains at a fixed location. The viewer can certainly look all around and even incline his or her head, but views the display as if he or she were a seated spectator as he would do fromin the very best seat at a live event.

In this sense, the service can be viewed either in ultra definition on a large curved screen, which would be suitable for a group of viewers, or in standard definition using a head-mounted system in combination with a head-tracker, which would be suitable for an individual experience.

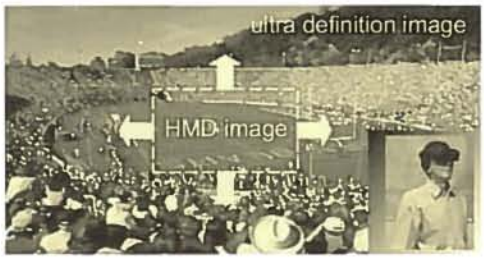

Fig. 1: Ultra-definition widescreen image and head-tracked head-mounted display (HMD image)

The video part of a first prototype receiver system, based on HD MPEG-2 technology, is currently under development at HHI for the ITC. Supposing that live action is being transmitted, the broadcast is limited to a reasonable bandwidth by transmitting one stream from a fixed-position HDTV camera and capturing the surroundings only occasionally or generating them synthetically. A dedicated merger unit, with ultra-definition capabilities, operates on seamlessly blended image segments to combine these visual media and to interface to different peripheral devices.

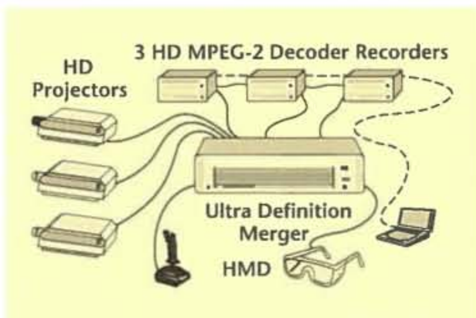

Fig. 2: Prototype receiver system

This work is supported by the Independent Television Commission, UK.

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HiCon – A Universal VLSI Architecture of Generic Video Format Conversion

A high-quality image converter architecture of moderate complexity has been developed at the Heinrich-Hertz-Institut. Single-chip integration is performed for applications in graphic displays and TV and HDTV sets. It will provide the highest possible video quality without motion artefacts or loss of resolution.

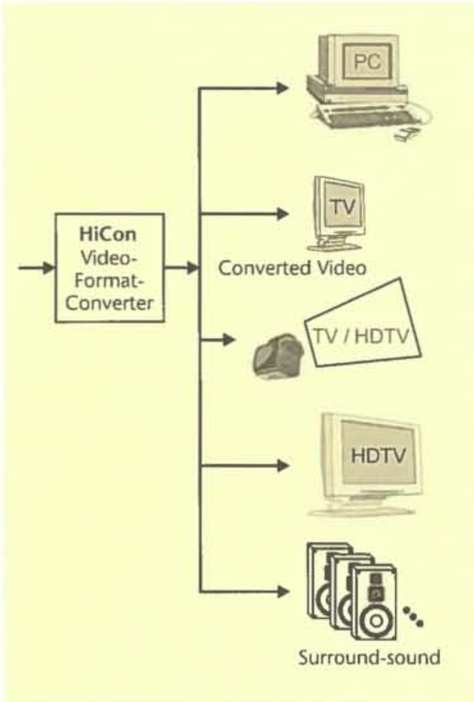
Image distortions resulting from the incompatibility of standards and formats occur if video that has been produced using common interlaced standards such as NTSC, PAL or ITU-R-601 is then progressively displayed on conventional computer monitors, high-quality TV screens (e.g. plasma displays), projection displays or high-resolution HDTV screens.

Only motion-compensating format conversion can solve these problems. This technology has so far been limited to high-cost applications because motion compensating techniques were very complex and expensive. However, a new image converter architecture based on motion compensation has been designed that combines high image quality and low hardware complexity, and a corresponding VLSI architecture has been developed. The whole converter will fit into one ASIC plus external RAM. This permits various applications (see figure).

The main applications are for progressive displays of motion video that has been produced in the 625/50 Hz 2:1 (PAL) or 575/60 Hz 2:1 (NTSC) interlaced standards. Progressive screens, such as plasma displays or large screen projectors, deliver flicker-free pictures. Additionally, the format converter can generate higher image rates with sufficient motion portrayal, as required for example in the conversion or CIF to progressive TV in for high-quality Video-on-Desktop. Furthermore, TV-to-HDTV conversion can be performed without loss of image resolution.

The real-time architecture of the converter presupposes VLSI integration because of the required processing speed. The design comprises a motion-estimation stage, an interpolation stage, a scaling filter, buffer memory, memory interface, control logic and I/O logic. Additionally, external image memory is needed to store up to six image fields and the motion vectors.

The slim design of the patented algorithm results in the restricted complexity of the computation stages for motion estimation and interpolation. Most of the hardware is taken up by the internal memory and the external memory interface. The problem of high access rates to the external memories is solved by the 64 bit wide memory interface. Hence, the complete converter module will require a gate count of about 1 Mgates. It is integrated in 0.25 µm technology. Two external SDRAMs are required in this design.



Applications of the converter

This work was supported by the German Ministry of Education, Science, Research and Technology (BMBF) under grant number 01 BK 514.

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Real-time Implementation of a DSP-based MPEG-4 Video Decoder

This paper describes the overall architecture of a DSP-based real-time MPEG-4 video decoder implementation based on the TMS320 C6201 signal processor from Texas Instruments. The video decoder was developed as part of the German national MINT project, which was funded by the German Ministry of Education, Science, Research and Technology.

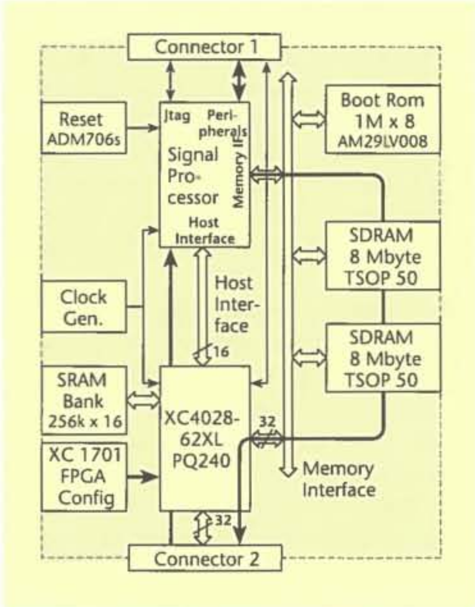
An MPEG-4 terminal for decoding, composing and presenting MPEG-4 audio and visual objects was required for the MINT project. Since the terminal should be PC-based, all needed functionalities had to be implemented in a PC environment. A first evaluation of the required performance was carried out, based on an MPEG-4 video decoder "C" programming language reference model. In view of the large computational power needed for decoding MPEG-4 video objects, it was decided to implement a DSP-based video decoder.

Since the first version of the upcoming multimedia standard MPEG-4 would be available only in the first quarter of 1999, it was necessary to use a very flexible hardware platform for the implementation of the MPEG-4 real-time video decoder, in order to be able to track all changes in the MPEG-4 standard over the time of the standardization process.

The first member of the TMS320 C6000 high performance DSP family from Texas Instruments was introduced to the market at the time the project started. For the evaluation of the computational power and memory required for the MPEG-4 algorithms on the DSP, the software development suite from Texas Instruments was used. It was found that most of the algorithms required changes for real-time performance on a TMS320 C6201 at 200 MHz.

The major problem in achieving real-time decoding for CIF (352x288 pixel) resolution at a frame rate of 25 fps was the lack of sufficient internal data and program memory in the DSP. To overcome this problem, an optimization technique was used to achieve better memory usage by swapping data structures from the external to the internal data memory, without modifying the algorithms. A special software memory manager, using the DMA functionalities of the signal processor, was implemented to do this.

Using this pure software implementation on the DSP, without additional hardware support and assembly language constructs, an average performance of 35 fps for CIF resolution was achieved for the MPEG-4 core profile video decoder algorithms.



Block diagram of the DSP module

In parallel with the implementation and optimization of the video decoder software, a hardware platform was designed to integrate the DSP into the PC environment. To obtain a high degree of flexibility and reusability of the hardware, a small DSP module (1.7x4 inch) was designed. This consists basically of the DSP (TMS320 C6201 at 200 MHz) itself, a Xilinx FPGA (XC4028 to XC4062) for interfacing purposes and for future hardware extensions, and a large bandwidth SDRAM (2x8 MByte) memory. The figure shows the block diagram of the DSP module.

Future developments include a standalone version of the video decoder for mobile applications, in which the presentation of the decoded video data will be achieved using a TFT display.

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Hardware Implementation of an AAC MPEG-4 Audio Codec

For future multimedia applications in the audio area, AAC will be the core MPEG-4 standard. MPEG-4 AAC can be used in a wide range of applications such as the home cinema, internet audio and hand-held player/recorders. AAC combines the coding efficiencies of different techniques (high resolution filterbanks, prediction and Huffman coding) to achieve high quality at very low bit rates.

In audio quality tests, AAC has demonstrated very high quality compared to all currently known coding standards. AAC provides near CD quality at a very low bit rate (64 kb per channel). The AAC standard is also capable of handling up to 48 channels in one bitstream.

As well as realising the MPEG-4 video codec, a main goal of this project is to develop a good hardware AAC encoder/decoder with available technologies. A powerful floating point architecture is mandatory because of the large resource requirements of the AAC encoder, whereas the AAC decoder can be implemented on a 32 bit fixed point processor. These arithmetic-intensive algorithms can be implemented on a standard DSP or on dedicated ASICs with 0.35 - 0.25 m technology. HHI has evaluated different inexpensive hardware solutions for implementing an AAC codec.

The TMS320 C6x DSP series from Texas Instruments has been chosen for the implementation of the AAC codec. TI has made two code-compatible versions of this processor: the C62x fixed point variant and the C67x floating point variant. Based on these DSP platforms, various tasks have been done:

1) Implementation of an ANSI-C AAC encoder and decoder
2) Resource optimisation
3) Profiling on the DSP platform
4) Extraction of time-intensive algorithms to a library
5) Optimisation of the library for the DSP platform

A reference implementation is required to ensure the functionality of the AAC software and to estimate the resource requirements of the algorithm. An ANSI-C implementation allows the algorithm to be transferred to other hardware platforms without extensive modification.

The resource optimisation is the most time-consuming task, since algorithm modifications require extensive functionality tests to ensure that the encoder and decoder conform to ISO/IEC 14496-3.

The source code then has to be compiled and profiled on the desired DSP platform. This third step identifies the resource-consuming parts of the algorithm, which then have to be optimised and extracted into a library. These library functions ensure the optimal use of the DSP, and may also be used in enhanced implementations.

The table shows the decoding time for a 93 ms mono bitstream on a C62x processor with the ISO/IEC 14496-3 AAC decoder and with the HHI implementation. The decoding time of the ISO reference decoder is much too slow for a real-time application, whereas the HHI implementation can decode 17 audio channels in real time.

	ISO AAC Decoder	HHI AAC Decoder
Total:	135.72 ms	5.41 ms

Decoding time for a 93 ms audio segment

The AAC encoder is very complex and needs 30 times more performance than the AAC decoder, so that the library for the AAC encoder must be written in machine-specific assembler code.

A hand-held recorder/player using a solid state memory has several advantages over devices using drive mechanics, such as low power consumption and small product size. It is possible to store up to 34 minutes of high quality stereo audio with AAC on a 32 Mbyte flash card.

A future goal is to develop multichannel encoder/decoder hardware.

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CustomTV – MPEG-4 and MPEG-7 Functionality in Conventional MPEG-2 Distribution Systems

CustomTV was an ACTS project that was completed in November 1999 after 18 months work. The project addressed the crucial problem of how viewers will cope with the proliferation of TV channels and how they will navigate through the mass of multimedia information that is likely to be broadcast alongside conventional digital TV programs.

The CustomTV project was based on the premise that future TV sets must be able to select and present information and services according to each user's preferences or profile. The objective of CustomTV was to utilise the ability of the existing digital broadcast technology to transmit all forms of multimedia information as well as normal digital TV channels, without requiring a backchannel. All such streams should be associated with metadata descriptors that could then be used at each receiver to customise the information received. The way the screen is organised for the display should be according to viewers' preferences, as established either with an easy-to-use interface or by pre-recorded user profiles.

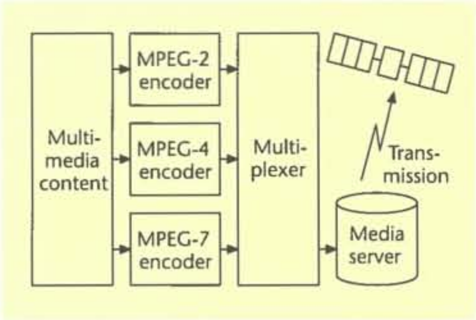

Fig. 1: CustomTV server

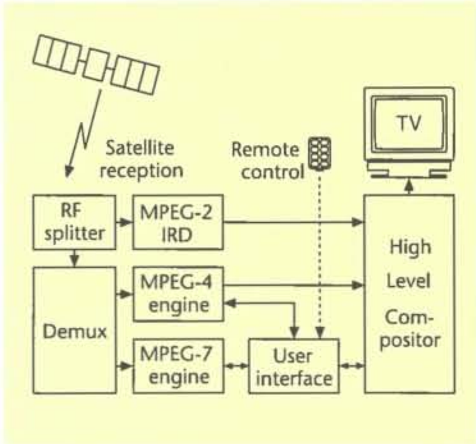

Fig. 2: CustomTV receiver

To achieve these objectives and to provide the user with new means of screen customisation, CustomTV relied on three main technologies: MPEG-2 for the transport of normal TV channels and private data, MPEG-4 for the broadcasting and manipulation of multimedia information, and MPEG-7 for indexing and filtering the information. As an enhancement of the current DVB service, the MPEG-4 and MPEG-7 elements had to be included as additional information in ordinary MPEG-2/DVB Transport Streams without corrupting the information already present. Thus, ordinary DVB receivers will receive the basic information as before, while enhanced receivers (such as the prototype developed by CustomTV) will also be able to fully utilise the enhancements.

The CustomTV demonstrator, which was shown at IBC '99 in Amsterdam, consists of the server-side equipment, a satellite link, and the real-time receiver, as shown in figures 1 and 2.

Decoding of MPEG-2, MPEG-4 and MPEG–7 data is done in real time. A commercial MPEG-2 Integrated Receiver Decoder (IRD) receives the RF signal from the antenna and outputs video and audio. An MPEG-4 engine, consisting of special software and hardware tools for demultiplexing, decoding and composition, was built. An MPEG-7 engine for decoding the MPEG-7 data, based on descriptors and a description scheme defined in the project, was also realised. CustomTV has contributed two proposals to the MPEG-7 standardisation process to secure the broadcasters' interests and to emphasise the broadcast application as a highly relevant area for MPEG-7.

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H. Boche, M. Schubert, **Verfahren und Anordnung zur Strahlformung für den Downlink-Kanal in CDMA-basierten Mobilfunksystemen (Technique and configuration for downlink beamforming in CDMA-based mobile communication systems)**, 199 43 688.6-35

E. Patzak, G. Großkopf, R. Eggemann, **Optisches Verzögerungsnetzwerk (Optical delay line network)**, 199 48 508.9-35

J. Liu, S. Pastoor, **Rechnerunterstütztes Verfahren zur berührungslosen, videobasierten Blickrichtungsbestimmung eines Anwenderauges für die augengeführte Mensch-Computer-Interaktion und Vorrichtung zur Durchführung des Verfahrens (Computer supported method for non-contact video-based gaze tracking)**, 199 53 835.2

V. Jungnickel, D. Razic, C. v. Helmolt, **Verfahren zur zeitlichen Kanalkodierung und –dekodierung für die digitale Puls-Positions-Modulation oder andere damit eng verwandte Modulationen und digitale Schaltungsanordnungen zur Verfahrensdurchführung (Encoding and decoding technique for digital pulse-position modulation)**, 199 58 025.1

HHI researchers have contributed to another five patents, filed by industrial partners from industry or research institutes.

AWARDS

G. Blättermann, **Joachim Tiburtius Preis 1999** for the Diploma Theses "Implementierung einer Best-Basis-Wavelet-Transformation zur Bilddatenkomprimierung (Implementation of Best Basis Wavelet Transform for Image Data Compression)", Nov. 1999.

R. Börner, **Nomination for DigiGlobe 1999**, category research and technology, subject "3-D Monitor", Aug. 1999.

Th. Ellerbrock, **Dissertation Award 1999 from the Westfälisch-Lippischen Universitätsgesellschaft** for the Doctorate Theses "Multilayer Neural Networks: Learnability, Network Generation, and Network Simplification", Nov. 1999.

E. Hilliger, **Studienförderpreis der Heraeus-Stiftung**, awarded for outstanding Diplomas in Physics in a short study time, Jan. 1999.

H.-G. Weber, E. Dietrich, S. Diez, H.-J. Ehrke, U. Feiste, E. Hilliger, H. Knupke, R. Ludwig, L. Küller, C. Schmidt, **Philip-Morris-Forschungspreis 1999**, for the research subject "Ultrafast All-Optical Switching Module for Communication Networks", June 1999.

H.-G. Weber, R. Ludwig, S. Diez, **Nomination for Zukunftspreis des Bundespräsidenten** (Innovation Award of the German Bundespräsident), for their outstanding scientific and technical innovation "Ultrafast All-Optical Data Switch for the Internet of the Future", Dec. 1999.

DOCTORATE THESES

Th. Engel, **Monolithische Photoempfänger zur Optik/Millimeterwellen-Konversion mit Metall-Halbleiter-Metall Photodetektoren und Heterostruktur-Feldeffekttransistor-Verstärkern auf InP (Monolithic photoreceivers for optic/millimeter-wave conversion with MSM-photodetectors and HEMT amplifiers on InP)** TU Berlin, Fachbereich 4 (Physik), Prof. Bimberg.

U. Feiste, **Theorie und Simulation dynamischer Prozesse in Mehrsektions-Halbleiterlasern (Theory and simulation of dynamic processes in multi-section semiconductor diodes)**, TU Berlin, Fachbereich 12 (Elektrotechnik), Prof. Petermann.

T. Fuhrmann, **Integriert-Optische Polymerfilter mit verteilter Rückkopplungsstruktur (Integrated optical polymer filter with distributed feedback)**, TU Berlin, Fachbereich 12 (Elektrotechnik), Prof. Petermann.

O. Schreer, **Ein Beitrag zur Stereobildverarbeitung und Navigation in der mobilen Robotik (A contribution for stereo picture compression and navigation in mobile robotic)**, TU Berlin, Fachbereich 12 (Elektrotechnik), Prof. Hartmann.

DIPLOMA THESES

M. Adamy, **Schichtenanalyse von High-electron-mobility-Feldeffekttransistoren mittels der Hall-Meßtechnik (Multilayer analysis of high-electron-mobility field effect-transistors using the Hall measurement technique)**, FHWT Berlin, FB 1. Supervisor at HHI: H.-G. Bach.

H. Aksünger, **Untersuchungen zur Auswirkung des Raman-Crosstals in transparenten optischen WDM-Kommunikationssystemen (Investigation of Raman crosstalk in WDM systems)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: E.-J. Bachus.

M. Braune, **Entwicklung und Erstellung eines Stromversorgungs-Sets für 40 Gbit/s-Empfänger-Module (Development and construction of a power-supply set for 40 Gbit/s-photoreceiver modules)**, FHTW Berlin, FB 1. Supervisor at HHI: H.-G. Bach.

A. Brückner, **Untersuchung der Übertragungseigenschaften von Knotenpunkten selbstheilender SONET-Ringsysteme (Investigation of the transmission properties of optical modes in self-healing SONET rings)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: E.-J. Bachus.

F. Bunjamin, **Entwicklung von Texturbeschreibungsverfahren für den MPEG-7-Standard (Development of texture description method)**, TU Berlin, Fachbereich 12 (Elektrotechnik). Supervisor at HHI: J.-R. Ohm.

J. Canivet, **Entwicklung eines Bistromanalysators fuer MPEG-4 Videodatenströme (Implementation of an MPEG-4 video bit stream analyzer)**, TU Berlin, Fachbereich 12 (Elektrotechnik). Supervisor at HHI: B. Stabernack.

H. Cimen, **Entwurf und Analyse eines richtungsabhängigen Kanalmodells für die Anwendung in breitbandigen Mobilfunksystemen (UMTS) (Design and analysis of a direction independent channel model for the application in broadband wireless communication systems (UMTS)**,TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: H. Boche.

Th. Eckhardt, **Entwicklung eines DIL-Lasermoduls mit einer Modulationsbandbreite von über 60 GHz (Development of a DIL-laser module with 60 GHz modulation bandwidth)**, FHTW Berlin, May 1999. Supervisor at HHI: U. Fischer.

K. Grünheit, **Entwicklung von Algorithmen zur Speicherreduktion in MPEG-Decodern (Development from algorithm for memory reduction in MPEG-decoder)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: J.-R. Ohm.

A. Höynck, **Entwurf und Implementierung von modifizierten Constant Modulus Algorithmen mit Anwendung auf das Beamforming von Antennenarrays für Mobilfunksysteme der 3. Generation (Design and implementation of modified constant modulus algorithms to be applied to the beamforming of antenna arrays for 3rd generation wireless communication systems)**,TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: H. Boche.

C. Huck, **Untersuchung der Wandlungsqualität eines bewegungskompensierenden Formatkonverters (Quality evaluation of a motion compensated video converter)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: M. Hahn.

D. Kouzian, **Erkennen von 3D-Objekten auf Fassadenoberflächen (Cognition from 3D-objects at facade faces)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: J.-R. Ohm.

O. Lietz, **Sprachgesteuerte Gesichtsanimation in MPEG-4 (Voice operated face animation)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: J.-R. Ohm.

A. Löffler, **Überwachung des optischen Signal-Rausch-Abstandes von WDM-Kanälen zum Management optischer Netze (Control of optical SNR in WDM channels for network management)**, Fachhochschule Offenburg. Supervisor at HHI: E.-J. Bachus.

R. Marzbanvishka, **Entwicklung eines hybriden Bewegungsschätzverfahrens (Development of a hybride method for motion estimation)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: J.-R. Ohm.

S. Meier, **Spektrale Rauscheigenschaften von InP-HEMTs mit Elektronenstrahlgeschriebenen Gates (Spectral noise properties of InP-based HEMTs with electron-beam written gate structures)**, FHTW Berlin. Supervisors at HHI: H.-G. Bach and G.G. Mekonnen.

Ö. Öcalmis, **Modellierung und Simulation von idealen Filtern unter Berücksichtigung des energetischen Verhaltens und Anwendung in der Mobilkommunikation (Modeling and simulation of ideal filters with regard to the energetic behaviour and to the application in mobile communication)**, TU Berlin, FB 12 (Elektrotechnik), Supervisor at HHI: H. Boche.

J. Pässler, **Implementierung eines Bitstromgenerators für MPEG-2 Transportbitströme (Implementation of a bit stream generator for MPEG-2 transport streams)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: B. Stabernack.

D. Przewozny, **Bildanalyse und -synthese für (auto)stereoskopische Multimedia-Displays (Image analysis and -synthesis for (auto)stereoscopic multimedia displays)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: J. Liu.

D. Razic, **Zählender 16-PPM Koder und Dekoder für die optische Mobilkommunikation (Counting 16-PPM coder for digital pulse-position modulation)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: V. Jungnickel.

U. Rebeschieß, **Einfluß der Richtcharakteristik verschiedener Constrained Beamformer auf die Bitfehlerrate des Aufwärts-Kanals von CDMA-basierten Mobilfunksystemen (Influence of the directional characteristic of different constraint beamformers on the bit error rate of the uplink channel of CDMA-based wireless communication systems)**,TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: H. Boche.

T. Ritter, **Signalverarbeitung bei Funkkanälen in Gebäuden in der zeitlichen und räumlichen Dimension (Space time signal processing for wireless indoor channels)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: H. Boche.

D. Rudolph, **Umbau eines Fineplacers zum Flip-Chip-Bondplatz zum Test von flußmittelfreien Lot- und Klebeverbindungen (Redesign of a fineplacer for fluxless flip-chip bonding)**, FHTW Berlin. Supervisor at HHI: U. Fischer.

A. Suna, **Herstellung und Charakterisierung von Laserstrukturen mit einer Emissionswellenlänge über 1700 nm (Fabrication and characterization of laser structures with emission wavelength $\lambda >$ 1700 nm)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: A. Paraskevopoulos.

B. Utus, **Charakterisierung wichtiger Parameter von Indoor-Mobilfunkkanälen und Untersuchung der Abhängigkeit der Parameter von der Raumgeometrie und der Frequenz (Characterisation of important parameters of wireless indoor channels and study of the dependence of these parameters on the room geometry and frequency)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: H. Boche.

P. T. Wildhagen, **Implementation and evaluation of numerical techniques for BER estimation in direct detection fiber optical communication systems**, TU-Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: E.-J. Bachus.

GRADUATE THESES

S. Askar, **Erweiterung des Stereomatchingverfahrens durch temporäres Matching von Stereobildfolgen mittels 2D-Tracking (Extension of a stereo matching method by temporary matching of stereo image sequences using 2D-tracking)**, TU Berlin, Fachbereich 12 (Elektrotechnik). Supervisor at HHI: J.-R. Ohm.

N. Brandenburg, **Entwicklung eines Disparitätsschätzers für eine nichtparallele Stereogeometrie (Development of a disparity estimator for a non-parallel stereo geometry)**, TU Berlin, Fachbereich 12 (Elektrotechnik). Supervisor at HHI: J.-R. Ohm.

Ch. Kulicke, **Implementierung und Test eines VLC zur MPEG-4 Videocodierung (Implementation and test of a VLC for MPEG-4 video encoders)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor HHI: B. Stabernack.

V. Pohl, **Diffuser für die optische Mobilkommunikation (Integrating sphere diffusor for mobile optical communication)**, TU Berlin, FB 12 (Elektrotechnik). Supervisor at HHI: V. Jungnickel.

ORAL PRESENTATIONS

H. Boche, **Randverhalten analytischer Funktionen**, Funktionstheoretisches Kolloquium, TU Berlin, 10.1.1999.

R. Schäfer, **HD technology – What can we use it for?**, ENST-Workshop "MPEG-4 & HDTV", Paris, France, 12.1.1999.

E.-J. Bachus, **Terabit communication networks using wavelength division multiplexing**, Seminar an der Technischen Fachhochschule Berlin, 13./20.1.1999.

H. Boche, **Konvergenzverhalten der komplexen Lagrange-Interpolation**, Funktionstheoretisches Kolloquium, TU Berlin, 17.1.1999.

R. Schäfer, **Endgeräte und Netze für Multimedia – Beiträge des MINT-Projekts**, Kolloquium „Produkte und Innovationen" des Mitteldeutschen Telematiknetzwerkes e.V., Leipzig, Germany, 20.1.1999.

J.-R. Ohm, **Digitale Bildcodierung – von der Signalkompression zum Visuellen Informationssystem**, Kolloquium RWTH Aachen, Institut für Nachrichtentechnik, Jan. 1999.

G. Heising, **A wavelet-based video coding scheme using image warping prediction**, Leipzig Video Coding Workshop, University of Leipzig, Institut für Informatik, 2.2.1999.

T. Tekin, **Monolithisch integrierte Interferometer**, Seminar zur optischen Nachrichtentechnik, Fachgebiet Hochfrequenztechnik, TU Berlin, 2.2.1999 und 18.6.1999.

H. Boche, **Notwendige und hinreichende Bedingungen für die Stabilität zeitdiskreter linearer Systeme**, Elektrotechnisches Kolloquium, TU Kaiserslautern, 11.2.1999.

A. Kortke, **Probleme bei der Anwendung eigenvektorbasierter Richtungsschätzungsverfahren auf planaren Antennenarrays**, ITG-Diskussionssitzung „Meßverfahren im Mobilfunk", Schloß Reisensburg, 3.-5.3.1999.

R. Schäfer, **MPEG-4, the Multimedia Standard for Interactive Services**, Kolloquium des DFN-Vereins, Berlin, Germany, 9.3.1999.

K.-D. Langer, **KomNet - Plattform zum Test photonischer Netztechniken und Komponenten**, ITG Fachtagung Photonische Netze, Dresden, 15.3.1999.

T. Haustein, **Breitband-Mobilkommunikation mit Infra-Rot-Technik „Fernsehen mit dem Handy"**, CeBIT 1999, Hannover, Talk im Turm, 17.3.1999.

H. Fresser[1], F. Prins[1], D. Wharam[1], D. Kern[1], J. Böttcher, H. Künzel, **Anticrossing von Energieniveaus in InGaAs Doppel-quantum-well Strukturen**, Frühjahrstagung der DPG, (Münster, Germany), 22.-26.3.1999.
[1] Universität Tübingen, D

H. Frey[1], H. Fresser[1], F. Prins[1], D. Wharam[1], D. Kern[1], J. Böttcher, H. Künzel, **Winkelabhängige Transportmessungen an InGaAs Doppel-quantum-well Strukturen**, Frühjahrstagung der DPG, (Münster, Germany), 22.-26.3.1999. [1] Universität Tübingen

C. Baack, **Das Internet 2005**, Fachgespräch Internet im BMBF, 15.4.1999.

T. Kuhwald, H. Boche, **Ein Algorithmus zur Erzeugung von Richtcharakteristiken mit maximaler Richtwirkung**, ITG-Diskussionssitzung „Systeme mit Intelligenten Antennen", Stuttgart, Germany 15.4.1999.

H. Künzel, **Molekularstrahl Epitaxie (MBE) für mikrostrukturierte Halbleiter**, Univ. Ulm, Germany, 18.4.1999.

C. Baack, **Das Zukünftige Breitband-Internet**, Industriemesse Hannover 99, 19.4.1999.

S. Diez, R. Ludwig, C. Schmidt, U. Feiste, H. G. Weber, **All-optical sampling of a 160 Gbit/s data signal using a novel gain-transparent four-wave mixing SOA switch**, WS COST, Rome, Italy, 22.4.1999.

H. Heidrich, W. Schlaak, **Bauelemente der Integrierten Optik**, Forum Techn. Transfer (FAIR '99), (Hannover, Germany), 24.4.1999.

M. Hamacher, H. Heidrich, R. Kaiser, P. Albrecht, W. Ebert, D. Franke, R. Gibis, G. Jacumeit, K. Janiak, R. Löffler, S. Malchow, W. Rehbein, H. Schroeter-Janßen, R. Stenzel, **Monolithisch integrierte Transceiver**, ITG-Workshop Photonische Integration und Aufbautechnik, Berlin, Germany, 5.5.1999.

L. Mühlbach, **Some experiences with IRC, webcams, and a virtual environment as means for informal communication**, 17th Int. Symp. on Human Factors in Telecommunications, Copenhagen, 5.5.1999.

H.-P. Nolting, B. Sartorius, **Novel functional devices for all-optical regeneration**, WS ACTS Photonic Domain, Brussels, 5.5.1999.

B. Quante, **Eye-contact in Multipoint Videoconferencing**, 17th Int. Symp. on Human Factors in Telecommunications, Copenhagen, 5.5.1999.

W. Schlaak, G.G. Mekonnen, H.-G. Bach, G. Unterbörsch, G. Jacumeit, R. Ziegler, R. Steingrüber, A. Seeger, A. Umbach, C. Schramm, W. Passenberg, **InP-OEICs für die 40 Gbit/s Datenübertragung**, ITG/VDE-

Workshop Photonische Integration und Aufbautechnik, Berlin, Germany, 5.5.1999.

H. Boche, **Beamforming Algorithmen für lineare Antennenarrays**, Elektrotechnisches Kolloquium, TU Karlsruhe, 6.5.1999.

B. Kuhlow, G. Przyrembel, **Der Einfluß von Fabrikationsfehlern binär optischer Fresnel-Zonenlinsen auf die Fokussierungsgüte**, DGAO-Jahrestagung, Berlin, Germany, 25.-29.5.1999.

T. Sikora, **MPEG-7 – A standard for content identification**, Deutsch-Japanisches Forum, Dresden, May 1999.

T. Sikora, **MPEG-7 – trends and perspectives**, Workshop Image Analysis for Interactive Multimedia Services WIAMIS '99, Berlin, 31.5.-1.6.1999.

H. Heidrich, **Photonische ICs für den Einsatz in zukünftigen photonischen Kommunikationsnetzen**, Phys. Inst. Univ. Stuttgart, (Stuttgart, Germany), 4.6.1999.

D. Marpe, **Wavelet-basierte Videocodierung unter Verwendung eines Blockverzerrungsmodells zur Bewegungskompensation**, Institut für Techno- und Wirtschaftsmathematik (ITWM) Kaiserslautern, 7.6.99.

D. Marpe, **A Wavelet-Based Coding Scheme Using OBMC and Warping Prediction**, ITG FG 3.1.2 Treffen, Rostock-Warnemünde, 11.6.1999.

R. Schäfer, **A contribution to H.26L Using Warping Prediction and Wavelet Decomposition**, Kolloquium der Universität Poznan, 21.6.1999.

J. Faber, T. Sikora, **Berlin als Online-City im 21. Jahrhundert**, Workshop from IHK Berlin and Deutsche Telekom AG, Bad Saarow, 25./26.6.1999.

T. Sikora, **MPEG-4 and its potential for digital media applications**, Media Streaming Workshop, London, 28./29.6.1999.

K. Müller, **Wavelet-basierte Konturcodierung**, ITG-Fachgruppe 3.1.2, Rostock, June 1999.

J.-R. Ohm, **MPEG-7 – ein Standard für Multimedia-Informationssysteme**, Workshop Objektbasierte Codierung und Multimedia-Informationssysteme, Universität Leipzig, Institut für Informatik, June 1999.

J.-R. Ohm, **MPEG-7 - ein Standard für Multimedia-Informationssysteme**, Kolloquium Universität Hannover, Institut für Theoretische Nachrichtentechnik, June 1999.

M. Radziunas, H.-J. Wünsche, B. Sartorius, H.-P. Nolting, K. Schneider, O. Brox, and D. Hoffmann, **Maßschneidern dispersiver Gütemodulation für die optische Taktrückgewinnung**, DFG Kolloquium „Optische Übermittlungsverfahren", Dortmund, 5./6.7.1999.

O. Brox, C. Bornholdt, D. Hoffmann, M. Möhrle, G. Sahin and B. Sartorius, **Selbstpulsierende DFB-Laser für die optische Taktregeneration**, DFG Kolloquium „Optische Übermittlungsverfahren", Dortmund, 5./6.7.1999.

M. Schlak, **All Optical Demultiplexing**, Alcatel – HHI Workshop, HHI Berlin, 9.7.1999.

H. Boche, **Konstruktion von Spreizsequenzen für CDMA-Mobilfunksysteme**, Elektrotechnisches Kolloquium, TU Kaiserslautern, 15.7.1999.

H. Künzel, **Present MBE related research activities at the HHI**, Hitachi Centr. Res. Lab, (Kokubunji, Japan), 21.7.1999.

T. Sikora, **MPEG-4 Video Coding Standard**, MPEG Seminar, Vancouver, Canada, July 1999.

C. Baack, **Netztechnologien für das Internet der Zukunft**. Workshop „Masterplan Internet 2005", BMBF, Wissenschaftszentrum Bonn, 4.8.1999.

G. Walf, **Photonik für das Breitband-Internet**, Seminar: Die Zukunft der Transportnetze, Frankfurt, 17./18.8.1999.

G. Großkopf, C. v. Helmolt, **Optical microwave generation and transmission experiments**, Workshop on Photonic Local Oscillators, Max-Planck-Institut für Radioastronomie, Bonn, Handouts, 23./24.8.1999.

R. Buß, **Advantages and disadvantages of virtual environments for supporting informal communication in distributed workgroups.** Human Computer Interaction International 1999, München, 26.8.1999.

K. Chantelau, J. Faber, T. Sikora, **Trends in der Informations- und Kommunikationstechnik der Gegenwart: Auswirkungen auf psychologische Entwicklungsarbeiten**, 7. Fachtagung zur Geschichte der Psychologie, Berlin, 27.-29.8.1999.

E.-J. Bachus, **Wieviel Bandbreite braucht das Internet?** Internationale Funkausstellung Berlin, Talk im TWF, 2.9.1999.

H. Heidrich, **Das optische Modem für Jeden**, Technical Scientific Forum (TWF) IFA '99, (Berlin, Germany), 2.9.1999.

R. Schäfer, **Der Kompressionsstandard MPEG-4 und seine Anwendungen**, Talk im TWF der IFA '99, Berlin, Germany, 3.9.1999.

R. Schäfer, **Dreidimensionales Fernsehen – Traum oder Wirklichkeit**, Talk im TWF der IFA '99, Berlin, Germany, 4.9.1999.

C. Baack, **A terabit testnet for the NGI infrastructure**, German-Israeli NGI Workshop, Neve Ilan, Israel, 6.-7.9.1999.

H.-P. Nolting, B. Sartorius, **Novel functional devices for all-optical regeneration**, WS COST 226, Zürich, 6./7.9.1999.

H.-P. Nolting, B. Sartorius, **Modelling of all-optical functional devices for signal processing: 3 R-regenerators**, Workshop Dynamics of Semiconductor Lasers, organized by WIAS, HHI, HU, Berlin, 9.-11.9.1999.

B. Sartorius, **Self-pulsating DFB lasers and their application for optical clock recovery**, Workshop "Dynamics of Semiconductor Lasers", organized by WIAS, HHI, HU, Berlin, 9.-11.9.1999.

K.-D. Langer, **KomNet – A modular platform to assess optical networking techniques and components**, 11^{th} Tyrrhenian Workshop on Digital Communications, Santa Margherita Ligure, Italy, 22.-25.9.1999.

R. Kaiser, M. Hamacher, M. Malchow, H. Heidrich, **Laser integration for transceiver applications**, Semiconductor Laser Workshop, Paris, France, 24.-25.9.1999.

K. Biermann[1], H. Künzel, **MBE Wachstum von AlGaAlnAs bei niedrigen Wachstumstemperaturen**, MBE-Workshop, (Würzburg, Germany), 27.-28.9.1999.

[1] Max-Born-Institut, Berlin, D

B. Stabernack, **Ein DSP-basierter MPEG-4 Videodecoder**, ITG Fachtagung, Dortmunder Fernsehseminar, Dortmund, 27.-29.9.1999.

H. G. Weber, U. Feiste, **Optische Signalverarbeitung für die hochratige Datenübertragung**, Photonik-Symposium, Duisburg, September 1999.

A. Kortke, **Kalibrierung von Antennenarrays für die dritte Mobilfunkgeneration**, Kleinheubacher Tagung, Schloß Kleinheubach, 27.9.-1.10.1999.

T. Haustein, **Mobilität und Multimedia – Trends und Perspektiven**, IFA 1999, Berlin, Talk im technisch-wissenschaftlichen Forum, live in the internet, 2.10.1999.

R.-P. Braun, R. Eggemann, G. Großkopf, E. Patzak, Short Course on **Optical microwave techniques, Part I – Fundamentals, Part II – Systems and Devices**, GAAS '99, European Microwave Week, Handouts, Session G-Sc2, Munich, Germany, 4.-8.10.1999.

R. Eggemann, G. Großkopf, E. Patzak, D. Rohde, **Optical delay networkstructure for 10 GHz true time delay antennas using semiconductor laser amplifiers as optical switching gates**, European Microwave Week, Workshop on Optical Technologies for Microwave Systems, M-FrW2, Handouts, Munich, Germany, 4.-8.10.1999.

R. Ludwig, **Ultraschnelle Halbleiterlaser durch Ionenimplantation**, Seminarvortrag im Hahn-Meitner-Institut Berlin, 19.10.1999.

G. Großkopf, H. Heidrich, **Optische Techniken und Komponenten zur Erzeugung und Übertragung von Mikrometersignalen**, Ferdinand-Braun-Institut, Berlin, Germany, 29.10.1999.

T. Kuhwald, H. Boche, **Beamoptimierung für Indoor-Anwendungen von Antennenarrays**, DFG Workshop „Indoor-Mobilkommunikation", Kassel, Germany 30.10.1999.

C. Baack, **Das Breitband-Internet der Zukunft**, Seminar für Photonik, Universität Karlsruhe (TH), 5.11.1999.

R. Schäfer, **Technologien für das dreidimensionale TV**, Info Comm. '99, Köln, Germany, 9.11.1999.

H.-P. Nolting, **Photonic integrated circuits for high-speed applications**, Optical Communication, In-depth Training Course by COBRA, IEEE/LEOS EUFORCE, Conference Centre De Kapellerput, Heeze, The Netherlands, 12.-14.11.1999.

H.-P. Nolting, **Functional devices for high-bitrate OTDM transmission and all-optical 3R-regeneration**, Workshop on Optical Communication (Opticke komunikace '99), Prague, 23.-24.11.1999.

C. Baack, **Die Bedeutung der Photonik für das zukünftige Internet.** Vortragsveranstaltung (Berliner Optik- und Laser-Kolloquium) der Technischen Universität Berlin, 30.11.1999.

J.-R. Ohm, **MPEG-7 – ein Standard für Multimedia-Informationssysteme**, Kolloquium FKTG und TU Ilmenau, Institut für Schaltungstechnik, November 1999.

R. Börner, **Autostereoskopische Displays – 3D ohne Brille**, Veranstaltungsreihe „Media Event" der Technischen Universität Ilmenau, 7.12.1999.

N. Grote, **MOVPE-basierende Zn-Eindiffusion in InGaAsP: Vergleich der Trägergase H^2 und N^2**, DGKK 14^{th} Workshop „Epitaxie von III/V-Halbleitern", (Stuttgart, Germany), 8./9.12.1999.

N. Grote, **Verbesserung des Grenzflächenverhaltens MOVPE-gewachsener InP: Fe-Schichten durch in-situ Substratätzen**, 14^{th} Workshop „Epitaxie von III/V-Halbleitern", (Stuttgart, Germany), 8./9.12.1999.

R. Schäfer, M. Hagemeister, H. Krahn, **Entwicklungstendenzen beim HDTV**, ITG-FG 3.1.1. Workshop „Trends der nichtlinearen Postproduktion und Entwicklung im HDTV-Bereich", München, Germany, 13.12.1999.

H. Heidrich, R. Ludwig, H.G. Weber, **Integrated photonic and optoelectronic components based on InP for high capacity transport and access networks**, Annual Meeting of IECE, (Tokyo, Japan), 14.12.1999.

LECTURES

H.-G. Bach, Physik und Technologie der Halbleiterbauelemente, TU Berlin

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

H. Boche, Digitale Mobilkommunikation I, TU Berlin

H. Boche, Digitale Mobilkommunikation II, TU Berlin

H. Boche, Hardy-Räume und Informationstechnik, TU Berlin

H. Boche, Intelligente Antennen und mehrdimensionale Signalverarbeitung in der Mobilkommunikation, TU Berlin

H. Boche, Kanalmodellierung und Simulation, TU Berlin

H. Boche, Space-Time-Signalprocessing für die Mobilkommunikation, TU Berlin

U. Fischer, Aufbautechnik für die optische Nachrichtentechnik, FHTW Berlin

B. Kuhlow, Einführung in die Photonik, TU Berlin

J.-R. Ohm, Bildverarbeitung I, TU-Berlin

J.-R. Ohm, Bildverarbeitung II, TU-Berlin

J.-R. Ohm, Bildsignalverarbeitung für Multimedia-Systeme, TU-Berlin

A. Paraskevopoulos, Halbleitertechnologie für die Integration in der Optoelektronik, TU Berlin

T. Sikora, Entwicklungstendenzen der Multimediakommunikation, TU Berlin

B. Stabernack, Komponenten der digitalen Bildsignalverarbeitung, TU Berlin

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

Ch. Weissig, Praktikum Digitale Systeme (MC-Labor), TU-Berlin

WORKSHOPS ORGANISED

HHI-press conference, Photonics for the Internet, Berlin, January.

Contribution for a TV-production, Einsteins Erben, topic Powerline-communication, station SFB B1, May.

ITG/VDE Workshop: Photonische Integration und Aufbautechnik, Berlin, May.

Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS '99), Berlin, May/June.

Photonic system modeling, "Integrated Photonics Research" Conference, St. Barbara, Ca, USA, June.

Dynamics of Semiconductor Lasers, Berlin, September.

Annual review of R&D programmes, KomNet, OptoSys and Photonik II, Berlin, October.

Press conference on the occasion of the annual review of R&D programmes KomNet, OptoSys and Photonik II, Berlin, October.

Internationale Funkausstellung (IFA '99): Wege des Internet Last Mile – Least problems?, September, 1999, Berlin.

Internationale Funkausstellung (IFA '99): Kompressions: Der Schlüssel zu Multimedia, September, 1999, Berlin.

CONTRIBUTIONS TO EXHIBITIONS

OFC '99, San Diego, February:
High speed components (jointly with u^2t)

CeBIT '99, Hannover, March:
„Mobil mit 140 Mbit/s" – Infrared free space data transmission for wireless bureau of the future, Broadband mobile communication

Industrie-Messse-Hannover '99, April:
PHASICs, 2D-holography

NAB '99, Las Vegas, April:
HiBOX2, HDTV-decoder box (jointly with DVB and MikroM)

Laser '99, München, June:
All optical clock, Diffractive Optics, Laser

IFA '99, Berlin, September:
Large multi-user plasma display, 40 inches diagonal with lenticular screen, User interface for an interactive multimedia TV, virtual video video conference (jointly with T-NOVA), digital terrestrial transmission of stereo TV, Teleworking in 3D with multi-modal interactions, HiPEG high definition MPEG-2 video decoder, HiCon high definition versatile video format converter, surround sound for electronic cinema

IBC '99, Amsterdam, September:
IMANA – The System for Rotoscopy, HiBox – a combination of efficient implementation of HDTV and sorround sound for home cinema, HDTV transmission via ATM fiber network, end-to-end system of CustomTV, selected scenarios that show added-value of MPEG-4 and MPEG-7 in a digital broadcast environment

ECOC '99, Nizza, September:
Mutli wavelength source, PHASICs (jointly with u^2t)

ICCC '99, Tokyo, September:
Virtual shop and virtual meeting point – Two prototype applications of interactive MPEG-4 services

3. Statusseminar Mobile Kommunikation, Berlin, September/October:
Audio-Video-Authoring-Tool für MPEG-4, MPEG-4 based 2D/3D-Compositor, real-time implementation of an MPEG-4 video decoder

Telecom '99, Genf, October:
Four wavelength WDM source (in cooperation with Krone)

Poster exhibition, Berlin, October:
on the occasion of the annual review of the R&D programmes KomNet, OptoSys and Photonik II

Europartenariat, Babelsberg, Oktober:
R&D activities of the HHI, search for future cooperation partners

COMMITTEE ACTIVITIES

Standardisation Committees

DVB Technical Module: Member

ISO/MPEG, Video Group: Chairman

VDI/VDE, Arbeitskreis Integrierte Optik: Member

Research Program Committees

COST 211: Member

COST 239, Management Committee: Member

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

COST 267, Semiconductor devices for signal processing WG2: Chairman

COST 268, Management Committee: Member (deputy)

IST (Inform. Society Technologies): Evaluator

Strategische Plattform Informationstechnik: Member

Conference and Workshop Program Committees

ECOC Technical Program Committee: Member

9^{th} European Conference on Integrated Optics (ECIO '99), 1999,Torino, Italy: Program Committee Member

European Conference on Multimedia Services, Applications and Techniques (ECMAST): Steering and Program Committee Member

Human Factors in Telecommunications: Permanent Steering Committee

Integrated Photonics Research Conference 1999 (IPR '99), St. Barbara, USA: Program Committee Member

International Conference on Transparent Optical Networks (ICTON '99, Kielce, Poland): Program Committee Member

International Picture Coding Symposium: Steering and Program Committee Member

Intern. Symp. Compound Semiconductors (ISCS '99, Berlin): Program Committee Member

International Workshop on Optical Waveguide (St. Etienne, France, '99): Program Committee Member

Laser Optik Berlin (LOB '99): Program Committee Member

Münchner Kreis, Congress „Anwender-freundliche Kommunikationssysteme": Program Committee

Münchner Kreis, Congress „Digitale Medien und Konvergenz": Program Committee Member

Münchner Kreis, Congress „Vision 21": Program Committee Member

Münchner Kreis, Congress „eCompanies founding, growing, harvesting": Program Committee Member

Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS '99), Berlin: Conference Chairman

Editorial Boards

EURASIP Signal Processing

IEEE Signal Processing Magazine: Associate Editor

IEEE Transactions on Circuits and Systems for Video Technology: Guest Editor

Image Communication: Associate Editor

Image Communication: Guest Editor

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

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

Advisory Boards

Photonic Network Communications

Other Committees

Arbeitskreis Integrierte Optik (AKIO): Member

Aspen Institut Berlin: Member

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

Eduard-Rhein-Stiftung: Board of Trustees

FKTG, Urtel-Preis-Komitee: Curatorship

IDR – Initiative Digitaler Rundfunk – Arbeitskreis MPEG-4

IFV – Interdisziplinärer Forschungsverbund Berlin

ITG, FA 3.1 Fernsehtechnik und elektronische Medien: Member

ITG, FG 3.1.2 Digitale Bildcodierung: Chairman

ITG, FA 5.3 Optische Nachrichtentechnik: Member

ITG, FG 5.3.1 Modellierung photonischer Komponenten und System: Committee Member

ITG, FG Optische Polymerfasern: Member

Münchner Kreis, Supranational Association for Communications Research: Research Committee

TSB-Technologiestiftung Innovationszentrum Berlin: Board of Curators

TWF (Technisch-wissenschaftliches Forum) IFA '99

WISTA-Management GmbH, Berlin: Advisory Committee

EXCHANGE PROGRAM

Scientists Visiting HHI

M. Aoki, Hitachi LTD Central Research Lab., Tokyo (J), financed by Hitachi, for one year

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

R. Freund, Fa VPI, Berlin, financed by VPI, for one year

A. Kovsh, A.F. Ioffe Physical Technical Institute, Russian Academy of Sciences of St. Petersburg (RUS), financed by HHI, for two months

V. Krajinovic, Technische Universität Wien (A), financed by TU Wien, for seven months

G. Levy-Yurista, Weizmann Institute of Science, Rehovot (IL), financed by HHI, for $^1/_2$ month

T. Li, Wuhan Research Institute of Posts and Telecommunication, Wuhan (PR China), financed by WRI, for two months

S. Schelhase, Advanced Photonic Systems, Berlin, financed by APhS, for one year

T. Taima, University of Tohuku, Sendai (J), financed by Univ. Tohuku, for two months

Mr. Wang, Wuhan Research Institute of Posts and Telecommunication, Wuhan, China, financed by WRI, for one month

X. Yang, Wuhan Research Institute of Posts and Telecommunication, Wuhan (PR China), financed by WRI, for three months

Z. Zhang, Wuhan Research Institute of Posts and Telecommunication, Wuhan (PR China), financed by WRI, for four months

S. Zhou, Wuhan Research Institute of Posts and Telecommunication, Wuhan (PR China), financed by WRI, for four months

HHI Scientists Visiting Foreign Institutes

N. Agrawal, Lucent Technologies, Holmdel, NJ (USA), financed by HHI, for one year

H. Heidrich, Communications Research Lab, Tokyo, (J), financed by HHI, for one week

H. Künzel, Hitachi LTD, Tokyo (J), financed by HHI, for two weeks

H. Preier, University of Linz (A), financed by HHI, for three years

COOPERATIONS

Industry

Advanced Photonic Systems, Berlin

Aifotec GmbH, München

Aixtron, Aachen

Alcatel SEL, Stuttgart

Alcatel, Paris

BAO Berlin Marketing Service GmbH, Berlin

Bayerischer Rundfunk, München

BBC, London

Bertelsmann, Gütersloh

Blaupunkt-Werke GmbH, Hildesheim

Bosch Telecom, Backnang

British Telecom, Martelsham Heath (GB)

Carl Zeiss, Jena, Oberkochen

Cybertron, Berlin

Czech Holography, Prague

DaimlerChrysler, Ulm

das werk, München

Deutsche Bank, Berlin

Dornier Satellitensysteme GmbH, Friedrichshafen

D-Research Digital Media Systems GmbH, Berlin

DSPecialist, Berlin

EPIGAP Optoelektronik GmbH, Berlin

Ericsson Eurolab, Aachen

Finanztest, Berlin

Fujitsu Mikroelektronik GmbH, Dreieich-Buchschlag

Hewlett Packard, Böblingen

Hitachi Central Research Laboratory, Tokyo

Holographie Design Berlin GbR, Berlin

Infineon Technologies, Berlin, Regensburg, München

INM – Institut für neue Medien, Frankfurt/M.

inm-numerical magic gesellschaft für neue medien mbh, Frankfurt/M.

ISIS Optronics, Darmstadt

KPN, Amsterdam

Krone GmbH, Berlin

Laser Components GmbH, Olching

Laser Spec GmbH, München

LKF Advanced Optics GmbH, Berlin

Loewe-Opta GmbH, Kronach

Lucent Technologies, Nürnberg, Holmdel (USA)

Mikroelektronik-Anwendungszentrum GmbH im Land Brandenburg (MAZ), Werder

Mikros Image, Paris

moove, Leverkusen

Nokia, Espoo (SF)

NTB Elektronische Geräte GmbH, Oranienburg

NTT, Tokyo

Opto+, Paris

OptoSpeed SA, Darmstadt and Mezzovico (CH)

Optotransmitter-Umweltschutz-Technologie, Berlin

Philips BV, Eindhoven

Planar International, Espoo (SF)

Prometheus Inc., Boston

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

Robert Bosch GmbH, Hildesheim, Stuttgart

Sentech Instruments, Berlin

SHF Design, Berlin

Siemens AG, Berlin, München, Regensburg

Sony UK, Sony Stuttgart

SYDIOS, Berlin

tandem Gruppe, Berlin

Tecsi, Paris

Telenor, Oslo

Teracom AB, Stockholm

Thomson CSF Optonique, Paris

T-Nova, Berlin, Darmstadt

u^2t Innovative Optoelectronic Components GmbH, Berlin

Vcon Telecommunications Ltd. (GB)

vision pearls, Berlin

Vodafone Ltd., Newbury (GB)

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

2SK Media Technologies, Berlin

Universities and Institutes

Brunel University, Uxbridge (GB)

Czech Technical University in Prague

Denmark Technical University, Kopenhagen

DFN-Verein, Berlin

ETH Zürich

ETRI, Taejon (Korea)

European Broadcasting Union, Genf

Ferdinand-Braun-Institut, Berlin

FhG Institut für Zuverlässigkeit und Mikrointegration, Berlin and Teltow

FhG Institut Siliziumtechnologie, Itzehoe

FHTW Berlin

Gesellschaft für Angewandte Optik und Spektroskopie e.V., Berlin

GMD, St. Augustin, Berlin

Hahn-Meitner-Institut, Berlin

Heriot-Watt University (GB)

Humboldt-Universität zu Berlin

INRIA, Paris

Institut für Physikalische Hochtechnologie – IPHT, Jena

Institut für Rundfunktechnik, München

Ioffe-Institut, St. Petersburg

IRISA, Rennes (F)

Konrad-Zuse-Institut, Berlin

Max-Born-Institut, Berlin

Max-Planck-Institut für Physik komplexer Systeme, Dresden

Paul-Drude-Institut, Berlin

Queen Mary Westminster College, London

Senatskanzlei, Berlin

Senatsverwaltung für Finanzen, Berlin

Stanford University, CA (USA)

TNO, Delft (NL)

Tohoku University, Sendai (J)

Tokyo University

TU Berlin

TU Braunschweig

TU Chemnitz/Zwickau

TU Darmstadt

TU Delft (NL)

TU Dresden

TU Ilmenau

TU München

TU Wien (A)

Universität Aachen

Universität Bonn

Universität der Bundeswehr, München

Universität Dortmund

Universität Erlangen-Nürnberg

Universität Jena

Universität Kaiserslautern

Universität Konstanz

Universität Stuttgart

Universität Tübingen

Universität Würzbug

University of Patras (GR)

Verbraucherzentrale Berlin e.V.

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

Weizmann Institute of Science, Rehovot (IL)

Wuhan Research Institute for Posts & Telecommunications (PR China)

Zentral- und Landesbibliothek, Berlin

START UP COMPANIES

LKF Advanced Optics GmbH, Berlin
LKF-Advanced Optics GmbH is a high-tech company, founded in 1996 by research staff members of the HHI. The mission is to convert the results of basic research to practical high end photonic components. First products are tunable mode-locked lasers in customized versions. Target for these products are leading telecommunication labs worldwide researching in ultra-high-bit time division muliplex technique.

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)
Virtual Photonics Incorporated (formerly BNeD GmbH and Virtual Photonics Pty Ltd) is a team of thirty executives and photonics engineers in Berlin, San Francisco and Melbourne delivering new design, planning and engineering software and services to leading component and system manufacturers, system integrators and network operators. VPI attracts the brightest talent in photonics engineering to design powerful software platforms, in partnership with the world's leading research institutes.
VPI invented the first generation of Photonics Design Automation systems products – BroadNed, GOLD and OPALS – and jointly developed the HPPhotonics System Designer. VPI has now consolidated and advanced this know how with the Photonics Transmission Design Suite, an integrated design tool for multi skilled corporate teamwork.

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^{2}t Innovative Optoelectronic Components GmbH, Berlin

u^{2}t Innovative Optoelectronic Components GmbH was founded in 1998 by three HHI scientists. Their intention is to support R&D-engineers with state-of-the-art optoelectronic components resulting from most recent device research. Ultrafast InGaAs photodetectors with 50 GHz bandwidth and extremely high power handling capabilities are the first products.

Usability Lab am HHI, Berlin

The company supplies Human Factors Support at all Stages of the Product Development Lifecycle. It helps to design all products of information technology with a high degree of usability. Thus, the chances of the product's successful future marketing will increase. But even products already on the verge of being put into the market can be improved by adopting Human Factors procedures.

vision pearls, Berlin

The company develops software for computer vision applications. The main interest is on video based human-computer interaction using advanced object detection and tracking algorithms. The first product will support new ways of interaction with multimedia software presentations.

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 iInterface module for HDTV projection systems compliant to the DVB and ATSC standard.

HHI AT A GLANCE

Government research institute (Federal Republic of Germany and State of Berlin)
Total staff at end of 1999: 246 employees

Areas of Research and Development

Photonic Networks

- Design, development and demonstration of optical communication networks and subsystems (access and customer networks, core networks)
- Investigation and development of WDM and high-speed OTDM techniques for high capacity transmission and routing
- Exploration of high speed transmission performance of photonic networks
- Development of techniques for network operation and maintenance
- Development and fabrication of photonic devices and integrated circuits (transmitters, modulators, switches, optical amplifiers, filters, multiplexers and demultiplexers, signal regenerators, transceivers, receiver frontends) based on InP, SiO_2/Si and polymers

Mobile Broadband Systems

- Development of space-time-receiver for the uplink of mobile communication systems
- Design of downlink beamforming for CDMA-based mobile communication systems
- Development of calibration algorithms for smart antennas
- Teletraffic engineering for mobile communication systems
- Development of signal processing algorithms for OFDM systems
- Development of sequences for CDMA applications
- Development of optical microwave generation and transmission systems for cellular mobile communication systems
- Development of RF and IR mobile systems for broadband in-house communication

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Electronic Imaging Technology for Multimedia

- Development of algorithms and hardware architectures for video and audio compression
- Development of algorithms and hardware architectures for image analysis and synthesis
- 3D Signal processing for tele-immersion
- Image processing for studio applications
- Video-streaming over IP and mobile networks
- Design of integrated circuits for image processing
- Development of 3-D display technologies
- Man-machine-interaction for future 3D-desktop applications
- Virtual reality for telework and telecommunication
- Development of user interfaces for multimedia applications
- Analysis and optimization of communication services
- Development of an optical pickup for DVD-systems

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