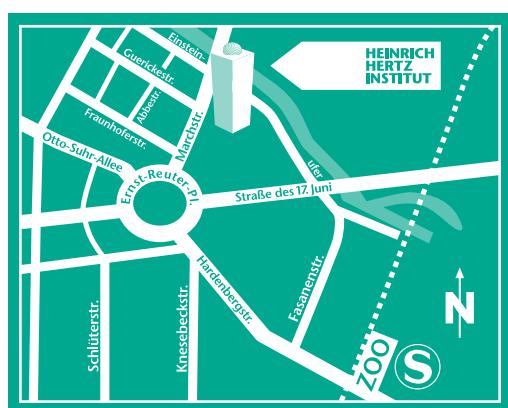
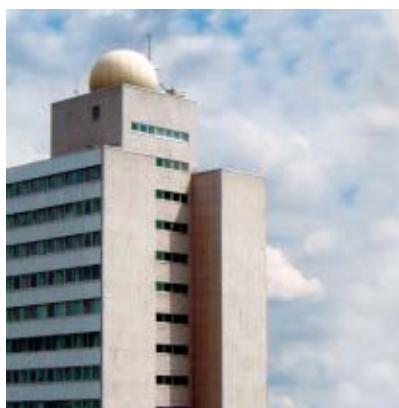


Annual Report Jahresbericht 2003





LIST OF CONTENTS

VORWORT PREFACE	2	The Office in a Box – Mobile Services for Citizens	59
LIST OF PROJECTS	6	Towards Semantic Search in Large Image Databases	60
LIST OF CHAPTERS	11	MPEG-7 Based Archiving and Retrieval of Digital Video	61
PHOTONIC NETWORKS AND SYSTEMS	12	IMAGE PROCESSING 62	
Optical Access Systems	17	im.point – The Immersive Meeting Point	68
Flexible Optical Networks/ Optical Burst Switching (OBS)	18	3D Scene and Object Reconstruction for Interactive Multimedia Services	69
Design of Next Generation Networks	19	Embedded Software Solutions for Video Processors in Mobile Phones	70
Evaluation of Optical Systems and Components for Industrial Applications	20	Facial Animation for Mobile Services	71
Raman Amplification in Next Generation Optical Networks	21	Adaptive Multimedia Streaming Using H.264/AVC	72
Optical Eye Monitoring of Data Degradations in Fibre Transmission Experiments	22	A DVB Compliant 3D-TV System	73
High Speed Transmission Using DPSK Modulation Format	23	BROADBAND MOBILE SYSTEMS 74	
PHOTONIC DEVICES	24	Optimal Transmission Strategy for the MIMO MAC with MMSE Receiver	78
Uncooled 10 Gbit/s Laser Diodes	30	Capacity of MIMO Systems with Closely-Spaced Antennas	79
1.55 µm DFB Laser with Integrated Spot-Size-Converter for Flip-Chip-Applications	31	Real-Time MIMO Transmission Experiments with Per-Antenna Rate Control (PARC)	80
Compact 40 GHz Pulse Laser Modules with Integrated Monolithic Mode-Locked Semiconductor Laser	32	Wireless Communications at 60 GHz	81
Selfpulsating Lasers as Pulse Source for RZ Modulation Format	33	FRAUNHOFER GERMAN-SINO LAB FOR MOBILE COMMUNICATIONS 82	
All-Optical Clock – A Key Device for Photonic Networks	34	Spectrally Efficient Multiantenna Systems	86
Semiconductor Optical Amplifier as Fast Optical Switch and its Application	35	OFDM New Air Interface	87
High-Bit Rate Mach-Zehnder Modulators	36	Cross-Layer Optimization of Wireless ad hoc Networks	88
Light Sources for Optical Sensor Applications	37	COMMUNICATIONS AND EVENTS 90	
40 Gbit/s Balanced Photoreceivers – Components for the Data Traffic on the Express Lane	38	Publications	90
Photodetectors for Fast Ethernet and Sensor Applications	39	Reports	96
Reconfigurable Polymer-Based Optical Add-Drop Multiplexer	40	Footnotes	97
PHOTONIC TECHNOLOGIES	42	Patent Applications	97
High Resolution Electron Beam Lithography – A Tool for Photonic Nanostructures	41	Awards	98
InGaAs/AlAsSb – A Material Basis for Ultra-Fast Photonics	42	Acceptance of Chairs	98
1.55 µm SIPBH Fabry-Perot Lasers	43	Doctorate Theses	98
Packaging of High-Speed Photonic Devices	44	Diploma Theses	98
INTERACTIVE MEDIA – HUMAN FACTORS	50	Graduate Theses	99
Free2C – High-Resolution Autostereoscopic Displays with User Tracking for Desktop and Kiosk Applications	51	Oral Presentations	99
A Family of Video-Based Tracking Modules for Interactive Media	52	Lectures	100
WORKBENCH ^{3D} – A Development Environment for Modelling and Visualization of Interactive Multimedia Applications	53	Workshops Organised	101
	54	Contributions to Exhibitions	101
	55	Committee Activities	101
	56	Exchange Program	102



Das Fraunhofer-Institut für Nachrichtentechnik als Innovationspartner

Innovationen werden aus Ideen geboren. Kreativität ist aber nur eine der notwendigen Voraussetzungen dafür, dass eine erfolgreiche Wertschöpfungskette entsteht. Hinzukommen müssen Erfahrung, Fachkompetenz und ein leistungsfähiges technologisches und wirtschaftliches Umfeld. Das Fraunhofer-Institut für Nachrichtentechnik – Heinrich-Hertz-Institut – besitzt ein exzellentes kreatives Potential. Darüber hinaus verfügen wir über Technologien, die es uns ermöglichen, zusammen mit der Industrie Innovationen von der Idee bis zum fertigen Produkt auszuführen.

Unser Institut zählt seit Jahren zu den Schrittmachern der modernen, digitalen Informations- und Kommunikationstechnologien. Unsere Kompetenzen umfassen das vollständige Spektrum vom „Physical Layer“ der Nachrichtentechnik – d.h. den photonischen Höchstgeschwindigkeitsnetzen und den breitbandigen Mobilkommunikationssystemen – bis hin zur Signalverarbeitung, den Endgeräten und den Anwendungen.

Trotz der einschneidenden Rezession in der IT-Industrie wächst das Verkehrsaufkommen in den Kommunikationsnetzen, namentlich im Internet, weltweit um über 100 % pro Jahr. Die sich entwickelnde Informationsgesellschaft verlangt nach einem nahtlosen globalen Netzwerk aus optischen Übertragungsstrecken und Vermittlungsknoten mit optischen Schalteinrichtungen, die das gesamte Feld vom Core- über den Access- bis hin zum Customer-Bereich umfassen und Zugangspunkte für das breitbandige mobile Kommunikationsnetz der dritten und vierten Generation bieten. Unsere Fachabteilungen für Photonik (siehe Fig. 1) entwickeln Lösungen für die ultraschnelle optische Signalverarbeitung und -übertragung auf Wellenlängen- und Zeitmultiplexbasis (WDM und OTDM) sowie photonische Bauelemente für das künftige Breitband-Internet (Indiumphosphid-Komponenten und opto-elektronische ICs, photonische Polymer- und SiO₂/Si-Komponenten).

Für mobile Breitbandsysteme untersuchen und entwickeln wir Netzwerke der nächsten Generation, die intelligente Antennen im Bereich von 2 – 60 GHz und Space-Time-Signalprocessing verwenden; beim Entwurf und der Implementierung von Algorithmen für Multiple-Input/Multiple-Output-Systeme sowie für CDMA- und OFDM-Systeme gehen wir bis an die signaltheoretischen Grenzen.

In unseren Fachabteilungen für Bildsignalverarbeitung und Interaktive Medien schaffen wir die Voraussetzungen für die Nutzung von Multimedia-Diensten auf den digitalen Netzen der nächsten Generation. Unsere Schwerpunkte

liegen bei der Videocodierung und Kompression für die robuste Übertragung über mobile Kanäle sowie bei der 2D- und 3D-Bildsignalverarbeitung. Wir entwickeln innovative Bildwiedergabetechniken, die das gesamte Spektrum von der Darstellung virtueller und gemischt-real er Umgebungen, über tele-immersive Systeme, HDTV und 3DTV-Großbildprojektionen bis hin zu Multiviewsystemen und autostereoskopischen 3D-Displays abdecken. Darüber hinaus entwickeln wir neuartige intuitiv nutzbare Mensch-Maschine-Schnittstellen, um die Gebrauchstauglichkeit und Nutzerfreundlichkeit künftiger mobiler und stationärer Endgeräte sicherzustellen.

Das Heinrich-Hertz-Institut ist am 22.10.2002 der Fraunhofer Gesellschaft beigetreten; das Jahr 2003 war somit unser erstes Geschäftsjahr unter FhG-Rahmenbedingungen. Unser wichtigstes strategisches Ziel bestand darin, die Zusammenarbeit mit der Industrie zu forcieren. Eine Fülle von Maßnahmen, wie z.B. die Benennung von Marketingbeauftragten, die interne Fortbildung in Innovationsmanagement, Projektmanagement, Qualitätsmanagement und Betriebswirtschaft und der verstärkte Auftritt mit produktnahen Ergebnissen auf Fachmessen, hat dazu geführt, dass wir unseren potentiellen Auftraggebern inzwischen attraktive marktorientierte Angebote machen können. Zur Stärkung des unternehmerischen Denkens und Handels wurden Entscheidungskompetenzen in die Fachabteilungen verlagert; die wirtschaftliche Ertragskraft der einzelnen Abteilungen wurde bei der Verteilung der Haushaltssmittel honoriert.

Dass das Institut ein von Wissenschaft und Industrie gleichermaßen geschätzter Partner ist und bleibt, belegt die große Zahl der nationalen und internationalen Workshops und Konferenzen, die wir entweder selbst organisiert haben oder an denen wir maßgeblich beteiligt waren.

Für herausragende persönliche Leistungen gab es mehrere Preise. Die bedeutendste Auszeichnung erhielt Professor Boche: den mit 20.000 € dotierten Forschungspreis Technische Kommunikation 2003 der Alcatel SEL Stiftung – als Beleg für wissenschaftliches Leistungsvermögen im Kontext mit industriellen Werten. Diese Preise sind Ermutigung und Ansporn für unser Institut im Fraunhofer-Verbund.

Insgesamt kann die aktuelle Situation wie folgt zusammengefasst werden:

- Das Heinrich-Hertz-Institut hatte 2003 im Durchschnitt 265 Mitarbeiterinnen und Mitarbeiter. Die Personalstärke ist in den vergangenen fünf Jahren relativ konstant geblieben.



- Mit den ca. 95 Projekten wurden im Jahr 2003 Erträge in Höhe von 14,3 Mio. € (siehe Fig. 2) und Investitionsmittel in Höhe von 2,7 Mio. € erwirtschaftet.
- Unser Institut genießt hohes internationales Ansehen in Wissenschaft und Industrie.
- Es verfügt über angemessene, teilweise einzigartige technologische Ressourcen.
- Es hat eine ausgewogene und hoch qualifizierte Mitarbeiterstruktur und ein gutes Betriebsklima mit reibungsarmer Zusammenarbeit der installierten Gremien.
- Unser Institut kooperiert eng mit Universitäten; einige Institutsangehörige nehmen Lehraufträge wahr und zahlreiche Diplomanden, studentische Hilfskräfte und Praktikanten beteiligen sich an unseren Projekten.
- Das Heinrich-Hertz-Institut hat den Wandel in Richtung marktorientierter F&E eingeleitet.

Es ist abzusehen, dass die nationalen Ressourcen für die Forschungsförderung in nächster Zeit stagnieren, wahrscheinlich eher noch abnehmen. Das Heinrich-Hertz-Institut wird schon deswegen sein F&E-Angebot stärker international ausrichten. Im EU-Raum sind F&E-Kooperationen via

Brüssel ein brauchbares Instrument für neue Partnerschaften mit der europäischen Industrie. Darüber hinaus besitzt der Ferne Osten attraktive Potentiale für die Nachrichtentechnik. Den Markt für mobile Breitbandsysteme in China werden wir in Zusammenarbeit mit Siemens und SEL Alcatel sowie chinesischen Partnern dort anstoßen. Zum Ausbau der Kooperation ist flankierend vom BMBF und dem chinesischen MOST (Ministry of Science and Technology) in einem Abkommen die Gründung des Sino-German Joint Software Institute (JSI) in Peking sowie des Fraunhofer German-Sino Lab for Mobile Communications (MCI) in Berlin beschlossen worden. Das JSI wurde im Oktober 2003 in Peking eröffnet, für das seit April 2003 geförderte MCI fand die offizielle Einweihungsfeier im Dezember statt. Ein Ausbau auf mindestens 30 Mitarbeiter auf jeder Seite ist geplant. Mit einem koreanischen Partner wird derzeit eine breit angelegte Kooperation für F&E in Korea sondiert.

Das Heinrich-Hertz-Institut fokussiert also sein Potential auf volkswirtschaftlich Wichtiges – der Umbruch hat Perspektive!

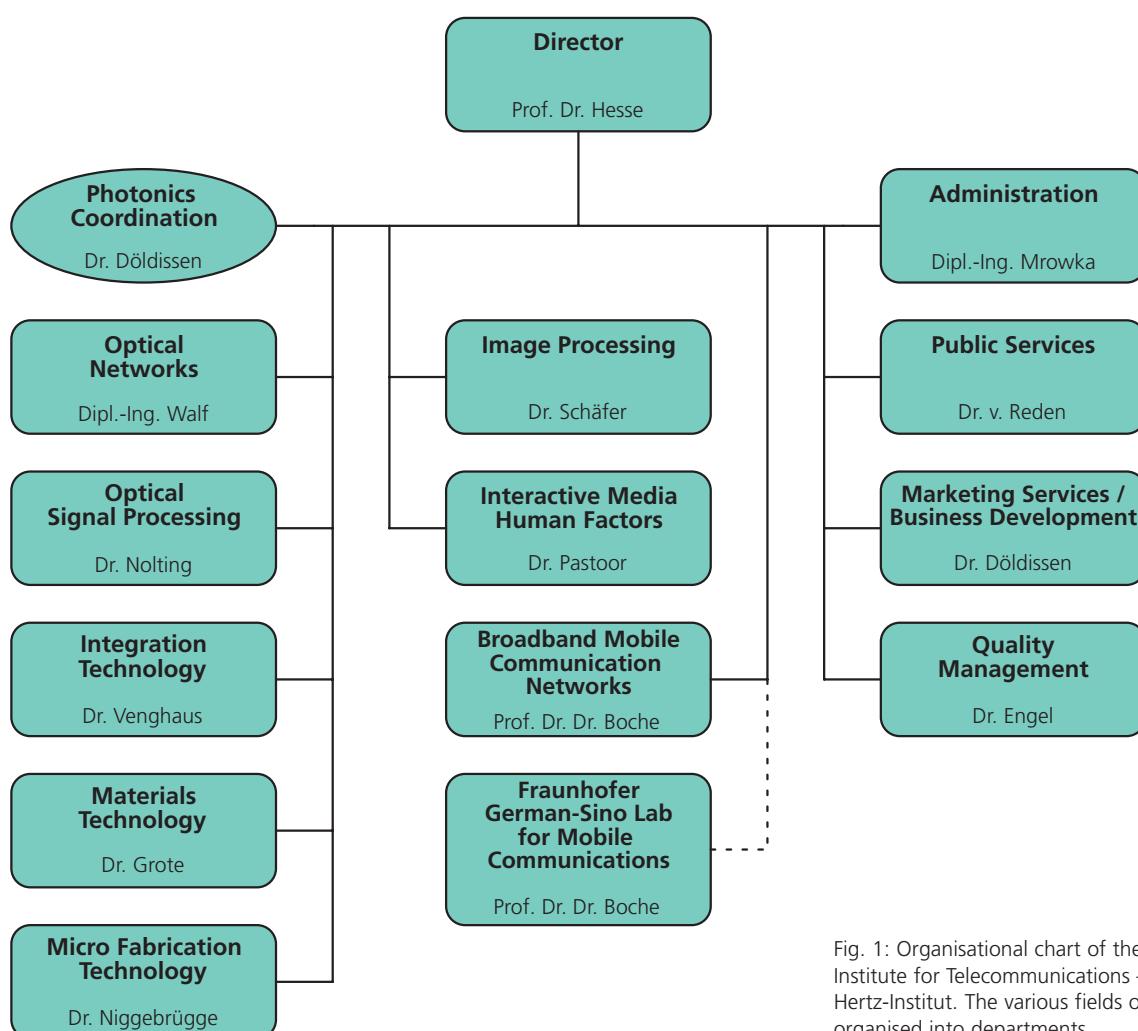


Fig. 1: Organisational chart of the Fraunhofer Institute for Telecommunications – Heinrich-Hertz-Institut. The various fields of activity are organised into departments

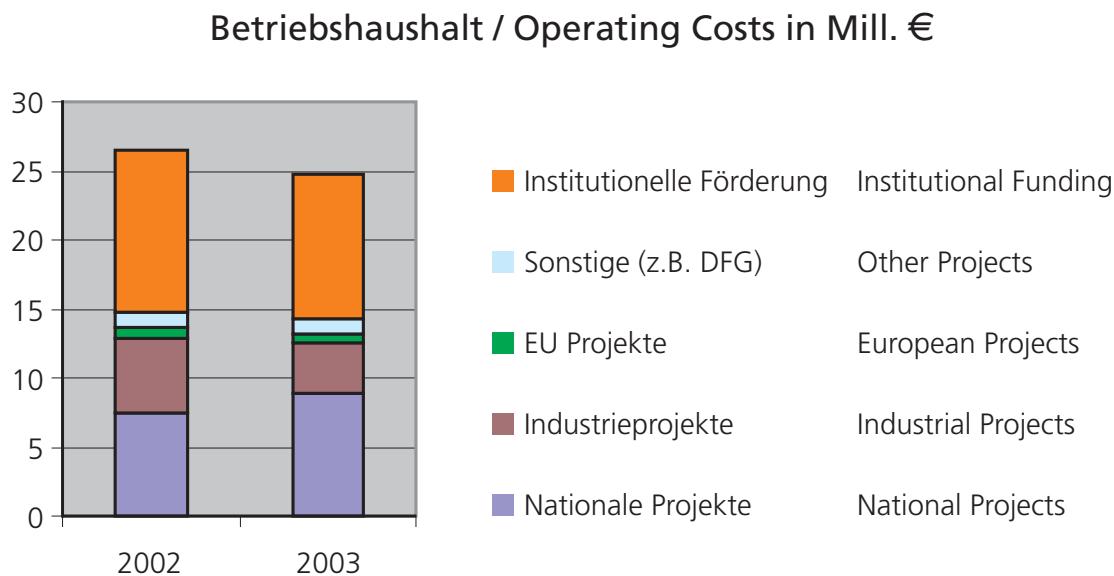


Fig. 2: Development of operating costs and sources of funding in 2002 and 2003

The Fraunhofer Institute for Telecommunications: Your Partner in Innovation

Innovation is born of ideas. Creativity is, however, only one of the necessary preconditions to ensure that a successful value-added chain is developed. On top of this, experience, professional competence, and an efficient, capable technological and economic environment are needed. The Fraunhofer Institute for Telecommunications – Heinrich-Hertz-Institut – not only possesses excellent creative potential, it also has at its disposal the most recent and innovative technology. This enables us to work closely and efficiently with partners from the industry to deliver innovations from the conceptual idea to the final product.

Our institute is a leader in the field of modern, digital information and communication technologies. We are competent in the full spectrum of technologies which extends from the “physical layer” of communication systems, i.e. the photonic high-speed and the broadband mobile communication networks, to signal processing, end systems, and user applications.

In spite of the dramatic recession in the IT industry, the amount of traffic in communication networks, namely in the Internet, continues to double almost every year. The emerging information society requires a seamless global network which consists of optical transmission links and routers and covers all areas from core to access. The photonic network also serves as the backbone structure for the fast growing broadband mobile communication systems of the third and fourth generation. Our photonics departments (see Fig. 1) develop solutions for ultra-fast optical

signal processing and signal transmission both on a wavelength and on a time-division multiplexing basis (WDM and OTDM). As key components for such networks, we develop photonic devices and subsystems based on InP semiconductor technology, complemented by optical polymers and SiO₂/Si structures.

For broadband mobile communication systems, we investigate and design networks of the next generation which employ smart antennas within the range from 2 to 60 GHz and space-time signal processing. We explore the limits of signal theory in order to derive and implement algorithms, e.g. for multiple-input/multiple-output, CDMA and OFDM systems.

Our departments working in the field of electronic imaging technology and interactive media create the foundation for next generation multimedia services. The main focus lies on video encoding and compression for robust transmission over wireless channels as well as on 2D and 3D image processing. We develop novel electronic imaging technologies covering the entire spectrum from virtual and mixed-reality environments to tele-immersive systems, HDTV and 3D-TV large-screen projections up to multi-view systems and autostereoscopic 3D displays. We investigate and design innovative, intuitively controllable human-machine user interfaces in order to enhance the accessibility and the user-friendliness of future mobile and stationary technical equipment.



The Heinrich-Hertz-Institut joined the Fraunhofer Gesellschaft on 22 October 2002. The year of 2003 was, therefore, the institute's first business year within the new framework. Our first strategic goal during that year was to improve the collaboration with private enterprises. We executed a broad range of measures such as nominating marketing managers, holding advanced training workshops in innovation management, project management, quality management and in business administration, with the goal of strengthening the entrepreneurial way of thinking and acting in our departments. Consequently, we have transferred the competence for decision-making to the departments themselves. We have also started to pay more attention to the profitability of our products and research and have increased our presence at commercial and technical trade fairs. As a result, we are in a strong position to make attractive market-competitive R&D offers to our potential clients.

The large number of national and international workshops and conferences which we have either organised ourselves or in which we have played a leading role is evidence of the high regard in which the institute is held. Both the academic community and private enterprises value us as a partner.

Members of our institute have received numerous awards for outstanding scientific accomplishments. One of the most prestigious research awards, the "Forschungspreis Technische Kommunikation 2003" of the Alcatel SEL Foundation, was given to Holger Boche, head of the Department for Broadband Mobile Communication Systems. These awards are proof of our scientific excellence and industrial relevance of our research work; they provide an encouragement and an incentive for our future work.

In summary, our present situation can be defined in the following terms:

- In 2003 the Heinrich-Hertz-Institut had on average 265 employees. The level of personnel was relatively constant over the last 5 years.
- 95 projects created a total income of 14.3 Mio. € (operating costs, see Fig. 2) and 2.7 Mio. € of investment.
- Our institute is held in high regard internationally both by the academic community and by industry.
- Our institute has at its disposal the appropriate technological resources with often unique capabilities.
- We have highly qualified technical staff, a good working climate, and an efficient interaction with the respective advisory bodies.

- Our institute co-operates closely with universities (some members of the staff hold teaching positions; several undergraduate and graduate students, student assistants and interns contribute to our projects).
- We have started to direct the focus of our R&D work towards market orientation driven by the needs of our customers.

It is expected that the level of national funding for research is going to stagnate and possibly decrease in the future. As a result, the Heinrich-Hertz-Institut has to focus increasingly on international R&D contacts. On the European scale, R&D collaborations via Brussels are the gateway to new contacts with the European industry. Beyond that, the Far East is an emerging region with a large potential for telecommunications. We are planning to enter the Chinese broadband mobile communications market in collaboration with Siemens, SEL Alcatel and Chinese partners. As a supporting measure, the German "Bundesministerium für Bildung und Forschung" (BMBF) and the Chinese Ministry of Science and Technology (MOST) have initiated in a mutual agreement the foundation of the Sino-German Joint Software Institute (JSI) located in Beijing and the Fraunhofer German-Sino Lab for Mobile Communications (MCI) in Berlin. The JSI in Beijing was inaugurated in October 2003. For the MCI, which was funded since April 2003 the official inauguration took place in December 2003. An expansion is planned to at least 30 employees at each side. We are also in negotiations with a Korean partner regarding a wide ranging R&D collaboration in Korea.

The Heinrich-Hertz-Institut, therefore, focuses its potential on economic priorities – the change has just begun!



Project	Project Manager phone eMail	Provider of Grant / Contractor Period
Photonic Networks		
Optical Technologies in Motion for the IST Programme, OPTIMIST	Erwin Patzak +49(0)30-31002-514 patzak@hhi.fhg.fhg.de	EU 5/00 – 4/03
Optical Technologies in Motion for the IST Programme II, OPTIMIST	Erwin Patzak +49(0)30-31002-514 patzak@hhi.fhg.fhg.de	EU 7/02 – 6/04
Innovation of Photonic and Mobile Communication Network for the Broadband Internet (TansiNet ON)	Godehard Walf/Jürgen Saniter +49(0)30-31002-455-288 Godehard.Walf@hhi.fhg.de/saniter@hhi.fhg.de	BMBF 6/00 – 12/03
Application of Distributed Raman Amplification for WDM Networks	Ernst-Jürgen Bachus +49(0)30-31002-586 bachus@hhi.fhg.de	DFG 3/02 – 5/04
Design of Switchable Optical Networks	Ernst-Jürgen Bachus +49(0)30-31002-586 bachus@hhi.fhg.de	BMBF (UMTS) 4/01 – 12/03
Development of Optimised Expanding Strategies for Wavelength Division Multiplex System for Applying a Maximum Transmission Datarate in Modern Fibre Infrastructures	Ernst-Jürgen Bachus +49(0)30-31002-586 bachus@hhi.fhg.de	BMBF (MultiTeraNet) 10/02 – 9/04
Dense Wavelength Division Multiplex and Internet Protocol	Ernst-Jürgen Bachus +49(0)30-31002-586 bachus@hhi.fhg.de	HHI 1/03 – 12/03
Control Modulation Technique for Client-Independent Performance Monitoring and Channel Identification in Transparent Optical Networks	Ernst-Jürgen Bachus +49(0)30-31002-586 bachus@hhi.fhg.de	DFG 4/02 – 21/03
Broadband Optical Access- and Inhouse Networking – Network Architecture and Protocols (ON)	Klaus Langer +49(0)30-31002-457 langer@hhi.fhg.de	BMBF (MultiTeraNet) 10/02 – 9/05
Optical Sampling of High Bitrate Data Signals	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.fhg.de	DFG 5/00 – 4/04
Gain-Clamped Optical Amplifier in Fibre-optical Transmission Systems	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.fhg.de	DFG 4/98 – 6/04
Active Resonant Grating-Waveguide Structures for Rapidly Tuning Semiconductor Lasers with no Moving Elements	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.fhg.de	BMBF 8/00 - 7/03
Saturable-absorber Switch	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.fhg.de	DFG 3/00 – 2/03
160 Gbit/s Transmission Techniques	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.fhg.de	Industry 11/01 – 3/03
Optical Time Division Multiplex Techniques for 160 Gbit/s and 640 Gbit/s	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.fhg.de	BMBF (MultiTeraNet) 10/02 – 9/05
160 Gbit/s Demonstrator	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.fhg.de	Industry 11/01 – 12/04
Integrated Circuits for a ETDM-Datatransmission in a 80 Gbit/s Single Channel	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.fhg.de	BMBF 1/01 – 12/03
Compression Techniques and System Investigations	Hans-Georg Weber +49(0)30-31002-443 hgweber@hhi.fhg.de	State of Berlin 1/03 – 12/05



Project	Project Manager phone eMail	Provider of Grant / Contractor Period
Transfer 40 GHz Optical Clock	Bernd Sartorius +49(0)30-31002-508 sartorius@hhi.fhg.de	Industry 4/02 – 6/03
High-frequency Selfpulsation of Multi-section DFB Laser	Bernd Sartorius +49(0)30-31002-508 sartorius@hhi.fhg.de	BMBF 2/01 – 2/04
Terabit per Second Optical Transmission Systems Based on Ultrahigh Channel Bitrate	Bernd Sartorius +49(0)30-31002-508 sartorius@hhi.fhg.de	EU 9/01 – 8/04
Optical 3R Regeneration for Asynchronous IP Networks	Bernd Sartorius +49(0)30-31002-508 sartorius@hhi.fhg.de	BMBF 7/01 – 12/04
Technical Development for OTDM Demultiplexers	Michael Schlak/Bernd Sartorius +49(0)30-31002-407/-508 schlak@hhi.fhg.de/sartorius@hhi.fhg.de	HHI 1/98 – 12/03
160 Gbit/s 3R Regenerator	Bernd Sartorius +49(0)30-31002-508 sartorius@hhi.fhg.de	Industry 11/01 – 6/03
Development of Future InP-based Laserdiodes	Martin Möhrle +49(0)30-31002-724 moehrle@hhi.fhg.de	State of Berlin IBB 1/02 – 12/03
Optical Subpicoseconds Pulses	Martin Möhrle +49(0)30-31002-724 moehrle@hhi.fhg.de	State of Berlin TOB 1/03 – 12/05
Innovative Lasers and Filters on InP Using Ring Oscillators	Helmut Heidrich +49(0)30-31002-538 heidrich@hhi.fhg.de	BMBF 4/00 – 3/03
Monolithically Integrated Picosecond Pulse Source	Helmut Heidrich +49(0)30-31002-538 heidrich@hhi.fhg.de	BMBF 10/00 – 9/03
Hybrid Integration on SOI Basis / Adapted Laser and SOA-OEICs	Helmut Heidrich +49(0)30-31002-538 heidrich@hhi.fhg.de	BMBF (MultiTeraNet) 10/02 – 9/06
Planar Photonic Crystals in Materialsystems with High Index Contrast	Helmut Heidrich +49(0)30-31002-538 heidrich@hhi.fhg.de	BMBF/VDI 2/02 – 1/05
Realization of high Order Optical Filters Using Active Coupled Microring Resonators	Helmut Heidrich +49(0)30-31002-538 heidrich@hhi.fhg.de	DFG 11/01 – 10/03
BH-Laser for High Bitrates	Jochen Kreißl +49(0)30-31002-525 kreissl@hhi.fhg.de	HHI 1/03 – 12/03
GaAs-Based 1300 nm Laser	Harald Künzel +49(0)30-31002-546 kuenzel@hhi.fhg.de	HHI 7/99 – 6/03
Lattice-matched MBE-growth of (In,Ga)As/(In,Al)As- and (In,Ga)As/Al(As,Sb)-Structures on InP for Intersubband Emitters	Harald Künzel +49(0)30-31002-546 kuenzel@hhi.fhg.de	DFG 9/00 – 8/03
Development and Fabrication of Surface-emitting (SE) DFB Laser Diodes	Martin Möhrle +49(0)30-31002-724 moehrle@hhi.fhg.de	Industry 10/03 – 3/04
MBE-Growth and Relaxation of Intersubband Transitions in (In,Ga)As/Al(As,Sb)-MQW-Structures	Harald Künzel +49(0)30-31002-546 kuenzel@hhi.fhg.de	State of Berlin (TOB) 8/03 – 7/06
Micro-Filter in Silica-on-Silicon Technology for Optical Communication	Berndt Kuhlow +49(0)30-31002-448 kuhlow@hhi.fhg.de	BMBF 4/00 – 3/03



R & D PROJECTS 2003

Project	Project Manager phone eMail	Provider of Grant / Contractor Period
Planar Integrated Waveguide-networks on Silica	Berndt Kuhlau +49(0)30-31002-448 kuhlau@hhi.fhg.de	HHI 1/01 – 12/03
Diffractive Optical Elements to Realise New Hybride Optical Systems	Margit Ferstl +49(0)30-31002-430 ferstl@hhi.fhg.de	Industry (HYBROS) 7/03 – 12/05
80 Gigabit Modulator Module	Karl-Otto Velthaus/Herbert Venghaus +49(0)30-31002-645/-555 velthaus@hhi.fhg.de/Herbert.Venghaus@hhi.fhg.de	BMBF (UMTS) 5/01 – 12/03
Electro-optical Modulator for Future Communications Networks	Karl-Otto Velthaus +49(0)30-31002-645 velthaus@hhi.fhg.de	BMBF (MultiTeraNet) 10/02 – 9/05
Development of a Phase Modulator for 80 Gbit/s	Karl-Otto Velthaus +49(0)30-31002-645 velthaus@hhi.fhg.de	State of Berlin (TOB) 8/03 – 7/06
Monolithically Integrated 40 GHz Pulse Source	Bernd Hüttl +49(0)30-31002-659 huettl@hhi.fhg.de	State of Berlin (TOB) 1/03 – 12/05
Potential Study for MQW-Structures	Norbert Grote +49(0)30-31002-241 Norbert.Grote@hhi.fhg.de	Technical University Berlin 10/03 – 3/04
Athermal AWG Based on Polymer	Norbert Keil +49(0)30-31002-590 keil@hhi.fhg.de	HHI 1/03 – 12/03
Integrated Optical Add/Drop Multiplexer Based on Polymer Technology	Norbert Keil +49(0)30-31002-590 keil@hhi.fhg.de	BMBF 7/01 – 6/04
New Applications of Polymers for Passive Optical Components	Norbert Keil +49(0)30-31002-590 keil@hhi.fhg.de	Industry 11/01 – 12/03
Advanced Packaging Technologies for Highest Frequency Opto-Electronic Components	Thomas Rosin +49(0)30-31002-221 rosin@hhi.fhg.de	BMBF (UMTS) 4/01 – 12/03
Development of Advanced Photodetectors Based on InP	Wolfgang Schlaak +49(0)30-31002-519 schlaak@hhi.fhg.de	State of Berlin IBB 1/02 – 1/04
10 Gbit/s Photodiodes	Wolfgang Schlaak +49(0)30-31002-519 schlaak@hhi.fhg.de	Industry 9/01 – 6/04
10 Gbit/s Photodiodes at 1,06 µm for a Test Model	Wolfgang Schlaak +49(0)30-31002-519 schlaak@hhi.fhg.de	Industry 8/03 – 6/04
Planar Selective Epitaxie	Anagnostis Paraskevopoulos +49(0)30-31002-527 Paraskevopoulos@hhi.fhg.de	Industry 11/01 – 12/03
Development of Novel Light Sources; Chip Fabrication and Fibre Coupled Modules	Anagnostis Paraskevopoulos +49(0)30-31002-527 Paraskevopoulos@hhi.fhg.de	Industry 1/02 – 12/03
1400 nm Pump Laser Source for TDFA	Anagnostis Paraskevopoulos +49(0)30-31002-527 Paraskevopoulos@hhi.fhg.de	BMBF (MultiTeraNet) 6/02 – 5/05
80/85 Gbit/s Photoreceiver	Heinz-Gunter Bach +49(0)30-31002-503 bach@hhi.fhg.de	Industry 7/02 – 1/04
Balanced Photoreceiver with High Bitrates	Heinz-Gunter Bach +49(0)30-31002-503 bach@hhi.fhg.de	Industry 8/03 – 12/04



Project	Project Manager phone eMail	Provider of Grant / Contractor Period
High Rate Optical Receiver for 80/160 Gbit/s	Heinz-Gunter Bach +49(0)30-31002-503 bach@hhi.fhg.de	BMBF (MultiTeraNet) 10/02 – 9/05
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Teletraffic Engineering for Packed Switched Services	Holger Boche +49(0)30-31002-540 Holger.Boche@hhi.fhg.de	HHI 6/00 – 5/03
Multiuser Receiver for CDMA Systems	Holger Boche +49(0)30-31002-540 Holger.Boche@hhi.fhg.de	HHI 6/00 – 5/03
OFDM New Air Interface Simulation	Holger Boche +49(0)30-31002-540 Holger.Boche@hhi.fhg.de	Industry 11/02 – 12/04
GBitWLAN	Clemens v. Helmolt +49(0)30-31002-506 Clemens.von_Helmolt@hhi.fhg.de	Industry 10/03 – 3/07
MULTIMODE: MIMO Techniques and Antennas	Clemens v. Helmolt +49(0)30-31002-506 Clemens.von_Helmolt@hhi.fhg.de	HHI 9/00 – 12/03
Intelligent Multi-Element Antenna- and Non-Orthogonal Multicarrier-Systems for Modern Broadband Mobile Communication	Clemens v. Helmolt +49(0)30-31002-506 Clemens.von_Helmolt@hhi.fhg.de	BMBF 11/00 – 12/04
Sequences in CDMA Systems	Holger Boche +49(0)30-31002-540 Holger.Boche@hhi.fhg.de	DFG 07/02 – 06/04
Optical Beam-formed Antennas for Adaptive Broadband Fixed and Mobile Wireless Access Networks	Gerd Großkopf +49(0)30-31002-317 grosskopf@hhi.fhg.de	EU 12/00 – 02/04
Broadband Optical Access- and Inhouse Networking – Network Architecture and Protocols (BM)	Gerd Großkopf +49(0)30-31002-317 grosskopf@hhi.fhg.de	BMBF (MultiTeraNet) 10/02 – 9/05
Electronic Imaging Technology for Multimedia		
Immersive Telepresence in the Internet	Peter Kauff +49(0)30-31002-615 Peter.Kauff@hhi.fhg.de	BMBF 7/00 – 6/03
Advanced Three-dimensional Television System Technologies, ATTEST	Peter Kauff/Klaus Hopf +49(0)30-31002-615/-581 Peter.Kauff@hhi.fhg.de/hopf@hhi.fhg.de	EU 3/02 – 3/04
Processor for Quality Improvement	Maati Talmi +49(0)30-31002-293 Maati.Talmi@hhi.fhg.de	State of Berlin, (IBB) 7/03 – 6/05
Bluetooth- and MPEG-4-based Key Components for Mobile Systems	Maati Talmi +49(0)30-31002-293 Maati.Talmi@hhi.fhg.de	BMBF (UMTS) 5/01 – 12/03
Development and Implementation of Algorithms and Structures for Video Projection by LC-Displays	Karsten Grüneberg +49(0)30-31002-262 Karsten.Grueneberg@hhi.fhg.de	Industry 9/02 – 3/03
Integrated Hardware Architecture for Multimedia Broad Image Project / TriMedia DSP	Karsten Grüneberg +49(0)30-31002-262 Karsten.Grueneberg@hhi.fhg.de	Industry 9/02 – 4/03
Open Multimedia Streaming Architecture	Detlev Marpe +49(0)30-31002-619 marpe@hhi.fhg.de	BMBF (UMTS) 4/01 – 12/03



R & D PROJECTS 2003

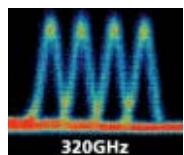
Project	Project Manager phone eMail	Provider of Grant / Contractor Period
Optical Information Systems for Traffic Analysis and Traffic Control / Videobased Traffic Monitoring	Aljoscha Smolic +49(0)30-31002-232 Aljoscha.Smolic@hhi.fhg.de	BMBF 9/01 – 12/03
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Algorithms for a 3D Realtime Videoconferencing System with High Telepresence	Ralf Schäfer +49(0)30-31002-560 Ralf.Schaefer@hhi.fhg.de	DFG 8/02 – 7/03
Highly Efficient TV-Transmitting in the DVB-T Network of Berlin and Brandenburg	Ralf Schäfer +49(0)30-31002-560 Ralf.Schaefer@hhi.fhg.de	State of Berlin 10/02 – 9/03
Image Analysis and Recognition in Information Systems	Thomas Wiegand +49(0)30-31002-617 Thomas.Wiegand@hhi.fhg.de	BMBF 6/01 – 5/04
Optimization of a Sequence Based Video Transmitting	Thomas Wiegand +49(0)30-31002-617 Thomas.Wiegand@hhi.fhg.de	DFG 5/02 – 4/04
Video Encoder Optimisation	Thomas Wiegand +49(0)30-31002-617 Thomas.Wiegand@hhi.fhg.de	Industry 1/03 – 6/04
Media Networking	Thomas Wiegand +49(0)30-31002-617 Thomas.Wiegand@hhi.fhg.de	EU 12/03 – 11/05
Adaptive Block Transform	Thomas Wiegand +49(0)30-31002-617 Thomas.Wiegand@hhi.fhg.de	Industry 11/03 – 3/04
Development of an Intelligent Vision Platform Including Pilot Applications for the Mass Market	Peter Eisert +49(0)30-31002-614 Peter.Eisert@hhi.fhg.de	Industry 5/02 – 4/05
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Intelligent Scalability for Interoperable Service	Stefan Rauthenberg +49(0)30-31002-266 Stefan.Rauthenberg@hhi.fhg.de	Industry 10/02 – 12/03
3D Techniques for Mixed-Reality Systems	René de la Barré +49(0)30-31002-345 Rene.De_la_Barre@hhi.fhg.de	BMBF 1/02 – 12/04
Mobile Services for Citizens	Lothar Mühlbach +49(0)30-31002-237 Lothar.Muehlbac@hhi.fhg.de	BMWA 10/02 – 9/04
MPEG-7 Based Analysis and Visualisation Tools for Archiving Digital Video	Thomas Meiers +49(0)30-31002-218 meiers@hhi.fhg.de	BMWA 4/02 – 3/05
Sensing People – Intelligent Cameras and Sensors	Ivo Keller +49(0)30-31002-387 keller@hhi.fhg.de	BMBF (UMTS) 9/01 – 12/03
Bringing User Satisfaction to Media Access Networks, BUSMAN	Thomas Meiers +49(0)30-31002-218 meiers@hhi.fhg.de	EU / IST 4/02 – 9/04
Photopatternable Light-Emitting Polymer MicroDisplays with Unique 3D Capability, PHOTOLEDD	Detlef Runde +49(0)30-31002-685 runde@hhi.fhg.de	EU /IST 1/03 – 12/04

List of Chapters



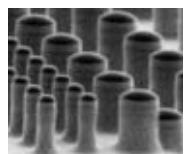
Photonic Networks and Systems

page 12–23



Photonic Devices

page 24–41



Photonic Technologies

page 42–49



Interactive Media – Human Factors

page 50–61



Image Processing

page 62–73



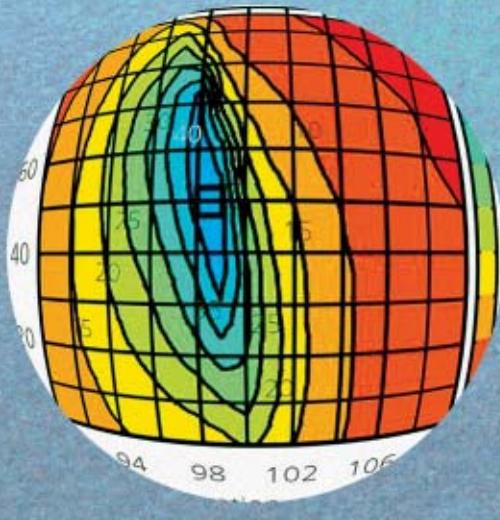
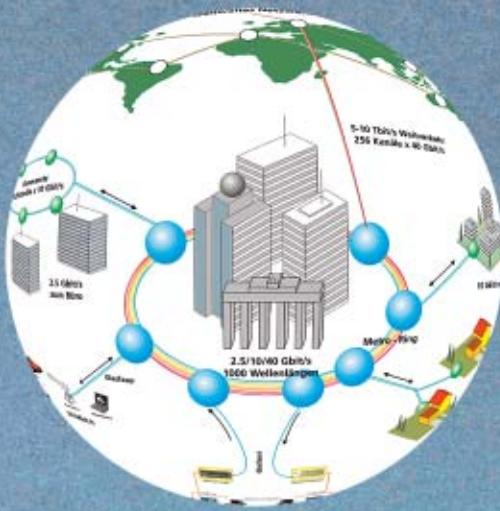
Broadband Mobile Systems

page 74–81



**Fraunhofer German-Sino Lab
for Mobile Communications**

page 82–89





Photonic Networks

Photonic networks are the foundation of modern worldwide communication systems. They consist of optical fibre systems with optoelectronic or optical switching nodes. Compared to traditional copper-based and radio frequency systems, the spectral width of the fibre transmission band is 70 Terahertz and offers virtually unlimited transmission capacity; it has led to the creation of the global data super highway. Telephone calls and the worldwide exchange of e-mails, graphics, video and other data across the Internet have been available at affordable cost. The creation of this information super highway ensured the triumphant success of the Internet, which has become an indispensable tool for everybody.

Despite the economic downturn of the IT industry traffic still doubles every year. Private and business users increasingly demand bandwidth for faster Internet access. One major problem, however, is the currently insufficient broadband access forming a bottleneck between the network and the user. The copper-based DSL-technology with moderate transmission rates in the Mbit/s range can only be an intermediate step towards a truly broadband fibre access (Fibre to the Home, FTTH). In some countries such as Japan, Korea, and the USA, there are – often highly subsidised – programmes to implement FTTx access with over 100 Mbit/s line rates for the private subscriber and several Gb/s for the business user.

The increasing use of the Internet is expected to result in bottlenecks in the core networks so that upgrades are necessary in the near future. Above all, a cost reduction in all network areas is necessary to provide the user with bandwidth at acceptable costs. This goal could be achieved by making the present static network more flexible and by using network resources more efficiently. With the so-called Next Generation Network (NGN), savings of up to 80 % can be expected.

Also, photonic networks are a prerequisite for the realisation of broadband mobile communication systems. The photonic network layer is necessary for the broadband connection between the base stations. In future pico-cell broadband mobile communication systems, an intelligent combination of wireless channels, base stations and optical interconnections will be required.

Since the 1970's, the HHI has been actively involved in the research and development of optical transmission systems and networks in cooperation with the industry and network operators. The HHI is among the few select institutes worldwide which have worked in the field of optical telecommunications from its inception and contributed decisively to its progress.



The main goal of present R&D activities is the use of new technologies and transmission schemes to achieve an improved utilisation of optical fibre transmission systems and increased capacity of photonic networks. This strategy covers all network aspects from the core, metro and access to the customer network. The nature of these investigations ranges from R&D tasks to purely physical-technical issues but also covers the development and test of management techniques for photonic networks and the interaction between protocol and physical network layer. The HHI carries out projects in collaboration with industry and network operators as well as within the framework of R&D-programs of the German Research Foundation (DFG), the German Ministry of Education and Research (BMBF), the State of Berlin and the European Union.

In the area of transmission technology, the institute carries out developments of low-cost-systems based on polymer fibre (POF) and R&D tasks for high capacity transmission systems using the entire available transmission band of the optical fibre. In this context, other important areas of active R&D are transmission rates up to 1 Terabit per second using optical time multiplex techniques, the full spectral utilization of fibre capacity by wavelength division multiplexing (WDM), novel dispersion compensation techniques, investigation of non linear effects, higher level modulation techniques, Raman amplification and all-optical 3R-regeneration.

In the area of photonic networks, the R&D activities focus on the investigation of optical nodes, circuit and burst switching, switching behaviour of networks, transparent transmission and network performance monitoring. One essential aspect of this work is the investigation of access network solutions including FTTH and coarse WDM systems using low-cost transceivers.

At HHI, well equipped state-of-the-art laboratories are available, which allow experiments pushing the boundaries of present day technology. A WDM fibre loop test bed is used for the experimental investigation of systems and networks with up to 16 wavelength channels and at bit rates up to 44 Gbit/s, which can be extended to additional transmission bands. In another high-speed laboratory, transmission experiments of currently 160 Gbit/s are carried out with the future goal of 1 Tbit/s on a single wavelength. All these R&D efforts are supported by computer simulations using sophisticated simulation tools.

Photonische Netze

Photonische Netze sind die Basis moderner weltumspannender Kommunikationssysteme. Sie bestehen aus optischen Glasfaserübertragungsstrecken und optoelektronischen oder optischen Vermittlungsknoten. Im Vergleich zu den traditionellen Übertragungsmedien auf Kupferbasis und zur Funktechnik bietet die Glasfaser mit einer Übertragungsbandbreite von 70 Tera-Hertz eine nahezu unbegrenzte Übertragungskapazität und ermöglichte in den vergangenen Jahren den Aufbau eines weltumspannenden Datennetzes. Durch die Glasfaser ist es möglich, zu sehr geringen Kosten in alle Welt zu telefonieren und per Internet E-Mails, Bilder, Videos, Daten usw. mit jedem Punkt der Erde auszutauschen. Erst durch sie war der Siegeszug des Internets möglich, dessen Nutzung für Jedermann mittlerweile ein Muss ist.

Trotz des Einbruchs in der IT-Branche verdoppelt sich das Verkehrsaufkommen in den Netzen weiterhin jedes Jahr. Die Teilnehmer – private wie geschäftliche – verlangen nach mehr Bandbreite, um z. B. schneller im World Wide Web surfen zu können. Ein großes Problem stellen die noch fehlenden „Auffahrten“, d. h. der breitbandige Anschluss der Teilnehmer dar. Die DSL-Technik auf der Basis der bestehenden Kupferleitungen mit moderaten Übertragungsraten im Mbit/s-Bereich ist nur ein Zwischenschritt zum breitbandigen Glasfaseranschluss. In Ländern wie Japan, Korea und USA gibt es bereits zum Teil hoch subventionierte Programme zur Einführung des optischen Anschlusses mit Übertragungsraten von über 100 Mbit/s für private und mehrere Gbit/s für geschäftliche Teilnehmer. Über den optischen Teilnehmeranschluss dringt die optische Technik quasi bis in das Wohnzimmer vor.

Mit der zunehmend intensiveren und breitbandigeren Nutzung des Internets zeichnen sich schon heute wiederum Engpässe in den Weitverkehrsnetzen ab, so dass in absehbarer Zeit deren weiterer Ausbau erfolgen muss. Darüber hinaus ist in allen Bereichen noch eine erhebliche Kostenreduktion erforderlich, um den Teilnehmern die gewünschte Bandbreite zu akzeptablen Kosten zur Verfügung stellen zu können. Dies soll u. a. durch eine Flexibilisierung der derzeit starren Netze und einer damit verbundenen besseren Nutzung der Netzressourcen erreicht werden. Bei dem sogenannten Next Generation Network (NGN) wird mit Einsparungen von bis zu 80 % gerechnet.

Auch für die breitbandige Mobilkommunikation sind die photonischen Netze eine Grundvoraussetzung. Über sie werden die Basisstationen breitbandig miteinander verbunden. In zukünftigen pikozellulären breitbandigen Mobil-



funknetzen ist ein intelligentes Zusammenwirken von Funkkanal, Basisstation und optischem Netz erforderlich. Das HHI führt bereits seit den 70er Jahren intensive Forschungs- und Entwicklungsarbeiten in Kooperation mit Industrie und Netzbetreibern zu optischen Übertragungssystemen und Netzen durch. Es gehört damit zu den weltweit wenigen Institutionen, die seit dem Beginn der Forschung auf dem Gebiet der optischen Nachrichtentechnik agieren und maßgeblich zum Fortschritt beigetragen haben.

Wesentliches Ziel der derzeitigen F&E-Aktivitäten ist es, mit neuen Techniken und Übertragungsverfahren eine bessere Nutzung der Glasfaserübertragungsstrecken sowie eine Steigerung der Leistungsfähigkeit photonischer Netze zu erreichen. Hierbei werden Netze vom Core- über den Access- bis hin zum Customer-Bereich betrachtet. Neben F&E-Arbeiten zu rein physikalisch-technischen Fragestellungen werden Untersuchungen und Entwicklungen zum Management photonischer Netze sowie zum Zusammenwirken der Protokollebenen mit der physikalischen Ebene durchgeführt. Das HHI bearbeitet die Themen im Auftrag von Industrie und Netzbetreibern sowie im Rahmen von Fördervorhaben des Bundes (MultiTeraNet, TransiNet), des Landes Berlin (TOB) und der EU.

Auf dem Gebiet der Übertragungstechnik werden Entwicklungsarbeiten für Low-Cost-Systeme auf der Basis von Polymer-Fasern (POF) bis hin zu F&E-Arbeiten für hochkapazitive Übertragungssysteme durchgeführt, bei denen das gesamte zur Verfügung stehende Übertragungsband der Glasfaser genutzt werden soll. Steigerung der Übertragungsrate in Richtung auf 1 Terabit pro Sekunde mit Hilfe der optischen Zeitmultiplextechnik, Nutzung der Faserkapazität durch Einsatz der Wellenlängenmultiplextechnik, Dispersionenkompensation, nichtlineare Effekte, höherwertige Modulationsverfahren, Ramanverstärkung und optische 3R-Regeneration sind wichtige Themen, die in diesem Zusammenhang bearbeitet werden.

Zum Thema photonische Netze erfolgen Untersuchungen zu optischen Netzknoten zur Leitungs- und Paket- bzw. Burstvermittlung, zum Schaltverhalten des Netzes, zur Transparenz und zum Performance-Monitoring. Einen wesentlichen F&E-Schwerpunkt stellen Untersuchungen zum kostengünstigen optischen Access-Netz dar.

Für die Untersuchungen stehen gut ausgestattete Labore zur Verfügung, die Experimente bis an die derzeitigen systemtechnischen Grenzen ermöglichen. Mit einem WDM-Loop-Testbett können System- und Netzuntersuchungen mit bis zu 16 Wellenlängenkanälen und einer Datenrate

von bis zu jeweils 44 Gbit/s durchgeführt werden. In einem Hochgeschwindigkeitslabor erfolgen Übertragungsversuche in Richtung auf 1 Tbit/s. Begleitet und gestützt werden die Untersuchungen durch Rechnersimulationen mit komplexen Simulationswerkzeugen.



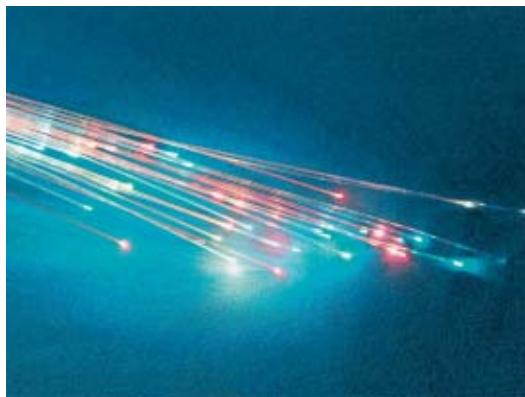
Photonic Networks and Systems

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Broadband Optical Networks	Jürgen Saniter	Phone e-mail	-288 saniter@hhi.fhg.de



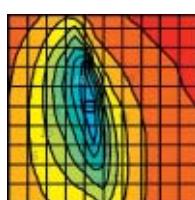
Optical fibres with a nearly unlimited bandwidth of 70 Terahertz are the transmission media for optical broadband communication networks



Implementation of photonic networks in all communication network areas for broadband for all: core, metro and indoor networks



Optical loop test bed for investigation and development of S-, C-, L-band wavelength division multiplex systems with transmission rates up to 40 Gb/s per channel



Simulation and design of photonic networks



OPTICAL ACCESS SYSTEMS

The importance of having powerful access to the Internet at moderate cost is growing rapidly. In several countries all over the world network operators are starting to fulfil the customers' increasing demand for bandwidth by means of optical subscriber loops with speeds that drop out classical copper-based DSL technology. In the field of optical fibre access networks, we are working on optimised ways that match the future needs.

Die Bedeutung von leistungsfähigen kostengünstigen Zugängen zum Internet nimmt rapide zu. In etlichen Ländern weltweit gehen die Netzbetreiber bereits dazu über, den steigenden Bandbreitebedarf ihrer Kunden mit Hilfe von Glasfaseranschlüssen und Übertragungsraten zu decken, die mit klassischer kupferbasierter DSL-Technik nicht machbar sind. Auf dem Gebiet der Glasfaserzugangsnetze arbeiten wir an optimierten Lösungen, die den zukünftigen Erfordernissen gerecht werden.

Today's speeds of access to communication networks are insufficient concerning modern multimedia and inter-

active applications. We can foresee that short-time bit rates from 100 Megabit/s up to several Gigabit/s are needed for residential and commercial customers, respectively. Without doubt, only access networks based on optical fibre technology can squarely meet such demands. Thus, it is conceivable to have an access network scenario for linking the customers to the central office as shown in Fig. 1.

For bundling multiple flows of traffic on a single fibre, coarse wavelength division multiplexing (CWDM) is rapidly gaining popularity due to the prospect of low cost solutions using uncooled laser diodes and passive components with relaxed performance specifications and packaging constraints. CWDM can be exploited also in order to achieve simple upgrading of transmission capacity by using some additional wavelengths. Moreover, protection mechanisms are considered to increase the safety against failures such as cable cuts or encroachments. But the introduction of new technologies like these need to consider available and emerging systems and components very carefully in respect to smart introduction and potential evolution, since the access network domain is extremely cost sensitive.

In the course of R&D projects on national and European scale, low-cost solutions for optical fibre access networks are developed and tested at our lab for access networks. The activities include conceptual work, calculations, simulations, experimental proofs of concept, and also system-oriented testing of key components such as light emitters. Vertical cavity surface emitting lasers (VCSEL) are expected to play an important role in optical access systems. As an example, the suitability of such lasers for use in access networks is tested in our labs, Fig. 2.



Fig. 2: Experimental set-up for testing VCSELs at wavelengths of 1.3 and 1.5 μm , which are most important in telecommunications. Rightmost shown is the device under test

We also evaluate the link performance for channels that can be upgraded to transmission speeds of 10 Gigabit/s. In this connection, the acceptable tolerances are determined for the major transmission parameters in order to achieve error-free transmission on link-spans up to 20 km.

We co-operate with both manufacturers and network operators, regarding not only technical aspects, but also issues like introduction and future extensions of optical fibre technology in the field. When doing such work it is also a crucial advantage to benefit from the wide basis of expertise at HHI's facilities, which covers most of the important areas on optical communications.

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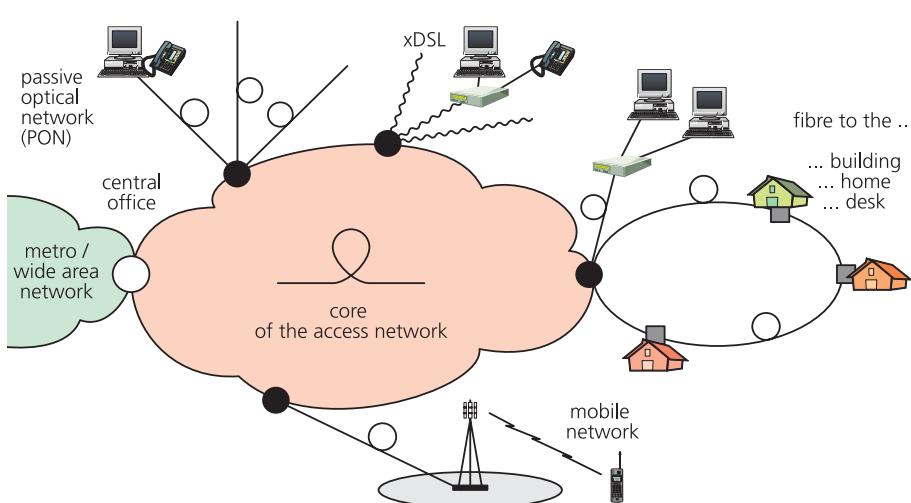


Fig. 1: Scenario of a fibre based access network enabling flexible and future-proof provision of broadband Internet access at the office, at home and en-route



FLEXIBLE OPTICAL NETWORKS / OPTICAL BURST SWITCHING (OBS)

On the way to flexible optical networks the implementation of a new system concept is only possible if the concept can be realised easily and cost-efficient. OBS is a promising candidate for a more dynamic optical layer, and our investigations show the feasibility and viability of OBS.

Auf dem Weg zu flexiblen optischen Netzen kann ein neues Systemkonzept nur dann zum Einsatz kommen, wenn es einfach und kostengünstig realisierbar ist. Mit unseren Untersuchungen über OBS wurden die grundsätzliche Machbarkeit und Entwicklungs-fähigkeit dieses viel versprechen-den Kandidaten für ein schnelles und dynamisches optisches Netz gezeigt.

In spite of present negative market conditions the Internet traffic has still grown exponentially during the last years. So the demand for more network capacity on the one hand, and low cost infrastructure on the other hand increases. Using dense wavelength division multiplexing (DWDM) technology the traffic carried by optical fibres can be increased cost-effectively up to several Tbps. In order to manage this traffic, it is necessary to route and switch at granularity levels adapted to these capacities. So switching functionality will be transferred more and more from electronics to optics. Fig. 1 shows a possible evolution of flexible optical networks.

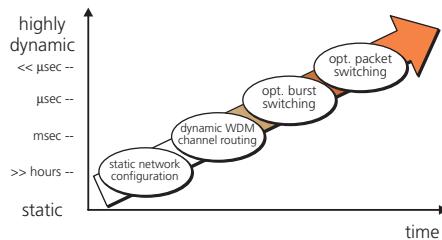


Fig. 1: Evolution of optical network technologies

The first step towards flexible optical network is the introduction of wavelength-routed optical networks. Then to use the network more efficiently, OBS will be a promising network concept. Longer packets (bursts) are aggregated at the edges of the burst switching network, and are transferred through the network using a one-pass-reservation scheme. The use of OBS will result in several new requirements on optical components and subsystems, e.g. fast and large switching nodes are required.

Due to the duration of bursts (between a few μ s and several 100 μ s), the switching time of OBS nodes should be well below 1 μ s. Our investigations have shown that the "Tune-and-Select" (TAS) switching nodes (Fig. 2) and its variations are promising OBS node architectures. The incoming burst is converted into the desired output wavelength by a tunable wavelength converter and then switched to the desired output fibre by semiconductor optical amplifiers (SOAs).

SOA gain saturation can be reduced substantially by using gain-clamped SOAs. We have explored two types of such gain-clamped SOAs (GC-SOA from Alcatel, and LOA from Finisar), experimentally and by numerical simulations, using realistic parameters. The results for TAS nodes with 4 input/output fibres and 3 different line rates (2.5, 10, 40 Gbps). are shown in Fig. 3.

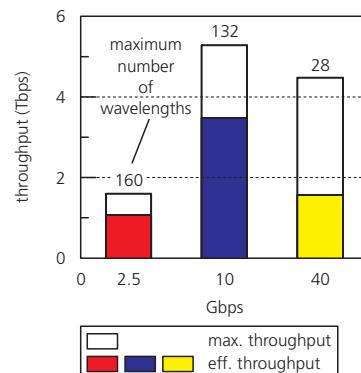


Fig. 3: Maximum number of wavelengths, maximum and effective throughputs for TAS nodes with four input/output fibres

The numbers above the bars show the maximum number of possible wavelengths by using GC-SOAs as

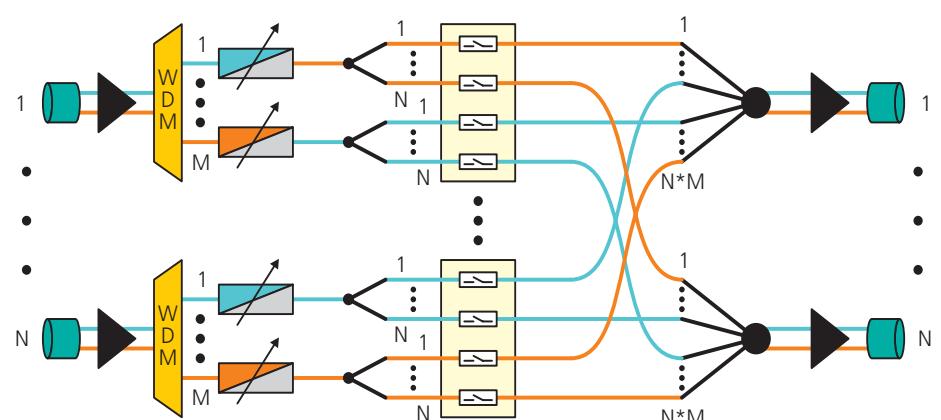


Fig. 2: Tune-and-select (TAS) switching node

The throughput of such OBS nodes is limited by signal degradation and burst losses. While the burst losses occur in case of contention at the output of a node, signal degradation is caused by several impairments. Amplifier noise, crosstalk of WDM channels, and the SOA gain saturation leads to signal distortion and reduce the possible node size dramatically.

gates. The transparent bars represent the maximum and the coloured bars the effective throughput for a Q-factor = 10 ($BER = 10^{-22}$) and a burst loss rate less than 10^{-6} . TAS nodes with 3.5 Tbps effective throughput can be built with gain clamped SOAs.

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DESIGN OF NEXT GENERATION NETWORKS

Trade-off analysis with respect to costs and performance play an important role when designing next generation networks. To reduce design costs, numerical simulations in combination with fibre loop experiments and field tests are used to reduce the number of design cycles (s. Fig. 1).

Entscheidende Größen im Design-Prozess zukünftiger photonischer Netze sind die Performance und die Kosten der in diesen Netzen zum Einsatz kommenden Übertragungssysteme. Die synergetische Nutzung von Simulations-Tools, Labor-Experimenten und Feldversuchen trägt hierbei erheblich zur Reduzierung der Entwicklungszyklen bei (s. Abb. 1).

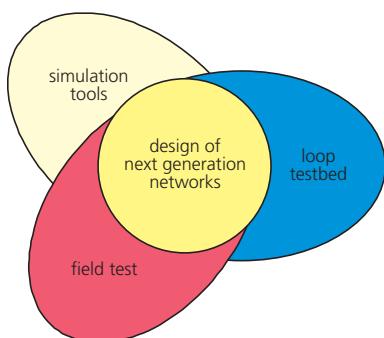


Fig. 1: Instruments for the design of next generation networks

Simulation Tools

HHI has a long tradition in developing simulation tools for the design of optical networks. As a spin-off of HHI, Broadband Network Design (BNeD) GmbH was founded in 1997. Today known as VPIsystems Inc., BNeD GmbH has grown up to a world leading supplier of network simulation tools.

HHI applies VPI software for the analysis of legacy network infra-structure and for the design of next generation networks. VPI and HHI have strong collaboration to realize the vision of Photonic Design Automation.

Fibre Loop Test-beds

In the early 90th, HHI started developing fibre loop test-beds for the investigation of all-optical core networks. Today, HHI is building up a 3-band (S-, C-, L-band) fibre loop test-bed for the investigation of high bit-rate (up to 40 Gbit/s per channel) and high capacity wavelength division multiplexed (WDM) systems to evaluate:

- Novel system concepts
- Sophisticated modulation formats
- Burst mode transmission
- Performance monitoring
- Raman amplification
- Simulation software

High-speed polarization controllers are used in the test-bed to replicate polarization properties of installed fibre links.

Field Tests

HHI has strong collaboration to Deutsche Telekom AG. Joined projects solve to evaluate simulated and lab-tested transmission systems under real operation conditions.

Example

For 10-Gbit/s-OOK-NRZ transmission, numerical simulations were carried out to find optimum operation conditions for a transmission section (s. Fig. 2) that consists of 80 km standard single mode fibre (SSMF), dispersion compensating fibre (DCF) and two Erbium-doped fibre amplifiers (EDFAs) to control fibre launch powers (PDCF, PSMF).

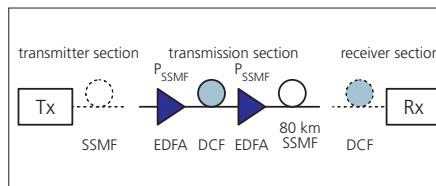


Fig. 2: Investigated Transmission Section

To find optimum dispersion map, additional SSMF in the transmitter section – a so called pre-dispersion – and DCF in the receiver section were considered.

Figure 3 shows the simulation results for the maximum number of cascadelable transmission sections versus the compensation ratio (CR) of chromatic dispersion and the ratio of pre-dispersion (PD) for optimum fibre launch powers. Best operation conditions can be achieved for under-compensated links (e.g., CR=99 %) and PD≈50 % (40 km SSMF).

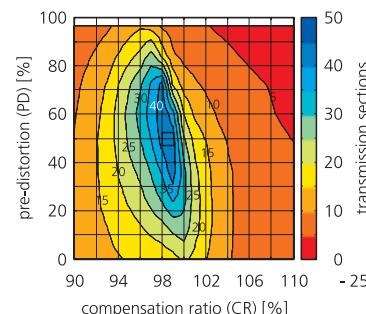


Fig. 3: Simulation results for the maximum number of cascadelable transmission sections to reach a receiver sensitivity penalty of less than 3 dB for a bit-error-ratio of 10^{-9}

Using fibre loop experiments (s. Fig. 4) and field experiments, these simulation results could be experimentally verified. As predicted by simulations, the system performance in the case of pre-compensation of chromatic dispersion can be drastically improved applying 50 % pre-dispersion.

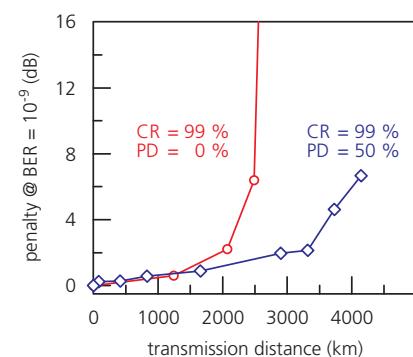


Fig. 4: Measured receiver sensitivity penalties for a bit-error-ratio (BER) of 10^{-9} and optimum fiber launch powers versus the number of cascaded transmission sections for CR = 99% with (PD = 50%) and without (PD = 0%) pre-dispersion

For the design of next generation networks, HHI offers access to pre-existing know-how, fibre loop test-beds and simulation capabilities.

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EVALUATION OF OPTICAL SYSTEMS AND COMPONENTS FOR INDUSTRIAL APPLICATIONS

A fully configurable WDM testbed is available for the experimental investigation of optical systems and components at bitrates up to 40 Gbit/s.

Für optische System- und Komponententests steht ein WDM-Testbett mit Bitraten bis zu 40 Gbit/s für eine Vielzahl von Messaufgaben zur Verfügung. Es kann nach Kundenwünschen konfiguriert werden.

Although simulation tools for optical systems get increasingly sophisticated, experimental evaluation of optical systems and components is indispensable. For this purpose, a WDM-testbed with a recirculating loop functionality is available at the HHI. This testbed acts as a fully flexible platform for a wide range of measurement tasks:

- Characterisation of photonic components and subsystems (all relevant optical and electrical parameters can be measured)
- Transmission tests for evaluating photonic components, subsystems and complete systems

A recirculating loop allows to emulate longer transmission distances or to perform cascading tests of components with a minimum of hardware effort. Fig. 1 shows the WDM-testbed. The standard configuration of the HHI recirculating loop has 16 WDM channels and a loop length of 160 km standard single mode fibre (SSMF). This loop is easily reconfigurable according to changing customer requirements and, therefore, a powerful tool for the following fields of application:

- Optical transmission bands from 1.3 to 1.6 μm

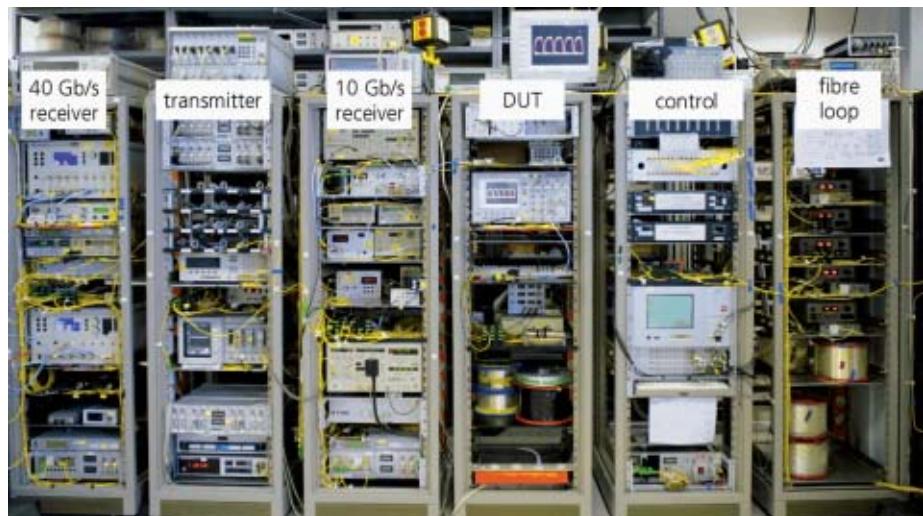


Fig. 1: WDM testbed with 16x 10 Gb/s or 16x40 Gb/s channels

- Coarse WDM and dense WDM
- Up to 40 Gb/s channel bit-rate
- Transmission over distances up to 10,000 km
- Doped fibre and Raman amplification
- Transmission over various fibre types
- Test of dispersion maps
- Comparison of modulation schemes (eg. NRZ-ASK, RZ-ASK, NRZ-DPSK, RZ-DPSK...)
- Analysis of polarisation effects
- Validation of simulation software by system tests

In the following, two examples of typical measurements in industrial applications are shown.

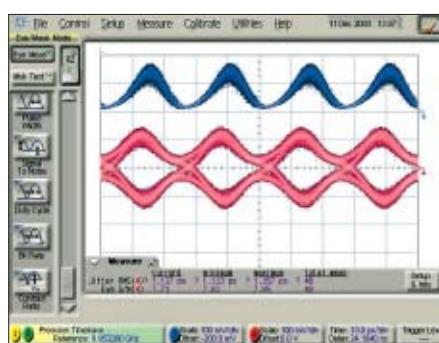


Fig. 2: 40 Gb/s RZ-DPSK signal (top) and eye diagram (bottom) measured with a balanced detector

In Fig. 2, a 40 Gb/s RZ-DPSK signal is displayed, an example of evaluating new modulation formats for transmission systems.

Fig. 3 shows the result of the investigation of new compact devices under test (DUT). The signal degradation, expressed by the penalty, is measured as a function of distance. These results are compared to a reference measurement with a widely-used standard device. This test has verified that the new compact DUTs are suitable for transmission distances up to 2000 km.

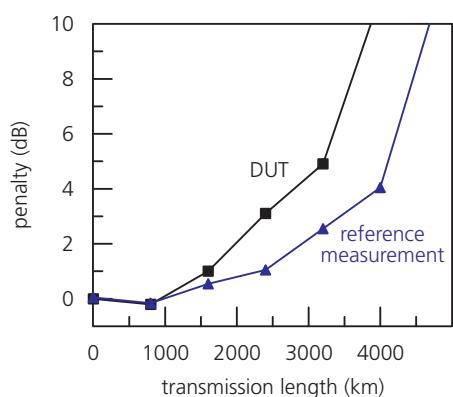


Fig. 3: Signal degradation for 10 Gb/s signals in the recirculating loop; new device under test (DUT) compared to a reference measurement with standard devices

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RAMAN AMPLIFICATION IN NEXT GENERATION OPTICAL NETWORKS

Raman amplification will play an important role in next generation optical networks because of its advantageous properties in comparison to Erbium-doped fiber amplifiers. Investigations at the HHI on non-switched and switched networks with both amplifier types have proven the better performance of Raman amplification especially in switched networks. Based on the experiences with WDM networks, the HHI network group is able to design and test advanced WDM systems with up to 40Gb/s according to the customers needs.

Die Raman-Verstärkung wird aufgrund ihrer vorteilhaften Eigenschaften im Vergleich zu Erbium-dotierten Faserverstärkern in Netzen der nächsten Generation eine bedeutende Rolle spielen. Untersuchungen beider Verstärkertypen am HHI in ungeschalteten und geschalteten Netzen haben gezeigt, dass die Raman-Verstärker, insbesondere in geschalteten Netzen, bessere Eigenschaften haben. Basierend auf den Erfahrungen mit WDM-Netzen ist es der HHI-Netzwerkgruppe möglich, fortgeschritten WDM-Systeme mit bis zu 40 Gb/s nach Kundenwünschen zu entwerfen und zu testen.

In next generation high-speed broadband WDM networks Raman amplifiers will replace a lot of the today's Erbium-doped fiber amplifiers (EDFAs) used at the links in order to extent the transmission band (from the C to the E, S, L and U- bands or beyond) and to improve the transmission capacity by higher data rates (≥ 40 Gb/s) and channel numbers.

At the HHI theoretical, simulative and experimental work has been done on 10 Gb/s and 40 Gb/s WDM systems using up to 16 channels and EDFAs.

Additionally distributed all-Raman amplified WDM systems with up to 16×10 Gb/s channels have been investigated. Transmission distances of 4000 km have been achieved using all-Raman amplification at the dispersion compensated fiber link of the HHI's fiber loop testbed transmission system.

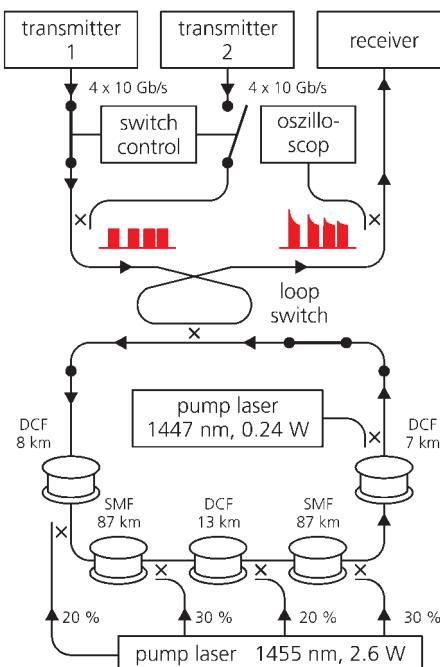


Fig. 1: All-Raman WDM loop transmission system with switched channels (8x 10 Gb/s, NRZ) (4 or 8 channels switched out of 8 channels)

To evaluate the dynamic properties of all-Raman and EDFA links, switched transmission systems with all-Raman amplification and all-EDFAs have been accomplished based on the fiber loop testbed. Fig. 1 shows the switched all-Raman system with 8 WDM channels

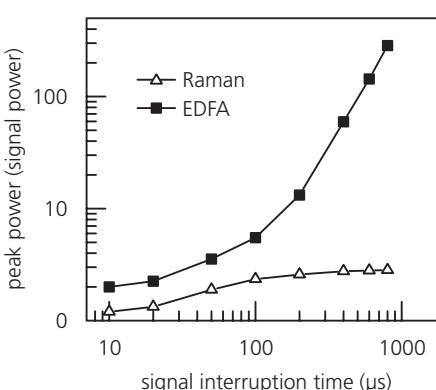


Fig. 2: Normalised signal power peaks caused by switching on and off all 8 signal channels for 10 to 800 μs

with 10 Gb/s NRZ signals where all or 4 out of the 8 channels were switched on and off.

Data burst of 200 μs length, interrupted by 10 to 800 μs gaps, have been transmitted over 200 km links and long-haul links of up to 2600 km and 65 cascaded amplifiers. The transmission experiments show that the signal power peaks at the switched channels, induced by amplifier saturation effects and switching of all channels, are much lower at Raman links than EDFA links (peaks are ≤ 3 times respectively ≤ 150 times larger than the signal power) (Fig. 2). Due to cross-gain effects, power peaks can be observed at the non-switched channels, too. Because of the moderate signal power peaks in switched Raman systems, the demands on amplifier gain control are moderate.

Taking advanced Raman pumping techniques into account, further advantages of the distributed Raman amplification can be achieved. This can be done by bi-directional and second-order Raman pumping which keep the link's signal power variations very low (≤ 1 dB) and therefore the noise and non-linear influences. One additional method is the application of a time-division multiplex pumping techniques with multi-wavelength pumps in broadband WDM systems. This avoids unwanted pump interactions, four-wave mixing effects and serious signal distortions. So, broadband systems with 1 to 3 gain bands of up to 100 nm can be accomplished using appropriate Raman pumping techniques. This, for example, enables the Raman amplification of coarse WDM signals using the 1300 nm to 1600 nm band. But even for smaller gain bands, Raman amplification offers a lot of benefits to achieve a gain equalisation, to reduce amplifier noise, and to provide amplifiers in the non-C-band, for example.

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OPTICAL EYE MONITORING OF DATA DEGRADATIONS IN FIBRE TRANSMISSION EXPERIMENTS

For the first time, we have experimentally analyzed the generation and dynamics of "ghost pulses" due to intra-channel four wave mixing (IFWM) at 160 Gb/s. We used an all-optical sampling system with a gain-transparent ultrafast nonlinear interferometer (GT-UNI) with an optical bandwidth of 210 GHz to analyze the nonlinear distortion of the eye diagrams.

Wir haben erstmalig experimentell bei einer Datenrate von 160 Gb/s die Erzeugung und Dynamik von „Geisterpulsen“ untersucht, die durch Vierwellenmischung innerhalb eines Wellenlängenkanals (IFWM) entstehen. Um die nichtlineare Verzerrung der Augendiagramme zu analysieren, haben wir ein rein optisches Sampling-System mit einer Bandbreite von 210 GHz verwendet, das auf einem GT-UNI basiert.

As the demand for capacity in the optical core network is increasing, there exists a growing industrial demand for high-speed fiber-optic transmission systems (40 Gb/s and above). In such systems for example, the maximum fiber input power which allows for error-free transmission, is limited by the nonlinearity of the fiber. It gives rise to a nonlinear effect known as intra-channel four-wave mixing (IFWM). Experimental investigation of IFWM, which causes so-called "ghost pulses", has been limited to bit-rates of 40 Gb/s up to now due to the limited bandwidth of photodetectors and electrical sampling oscilloscopes.

At HHI, an all-optical sampling system incorporating a clock extraction, a low jitter semiconductor mode-locked laser as sampling pulse source and a GT-UNI as optical sampling gate was developed and realized as laboratory prototype. The gating window width is 2.1 ps which corresponds to an optical bandwidth of 210 GHz.¹ This exceeds the bandwidth of a conventional optoelectronic sampling systems by a factor of 5. It allowed to investigate for the first time the generation and dynamics of ghost pulses due to IFWM at a data rate of 160 Gb/s by analyzing the measured eye diagrams and comparing them to the numerical simulations with respect to the intensity and temporal position of the generated ghost pulses.²

The experimental set-up is shown in Fig. 1. The 160 Gb/s optical test signal was generated by multiplexing the signal from a 10 Gb/s PRBS transmitter. It contained only two adjacent 160 Gb/s OTDM channels (1.5 ps sech² pulses) in order to clearly identify the nonlinear distortions in the eye diagram. It was launched into a fiber link consisting of non-zero dispersion-shifted fiber (NZDSF) and 100% dispersion compensation (SMF+DCF).

Fig. 2 shows the measured optical eye diagrams at different input peak powers. It can be seen that for high peak powers, ghost pulses were generated on each side of the test signal due to IFWM.

When evaluating the eye diagrams with respect to the intensities and temporal locations of the individual peaks, we found an asymmetry in the intensity and temporal position of the generated ghost pulses. Numerical

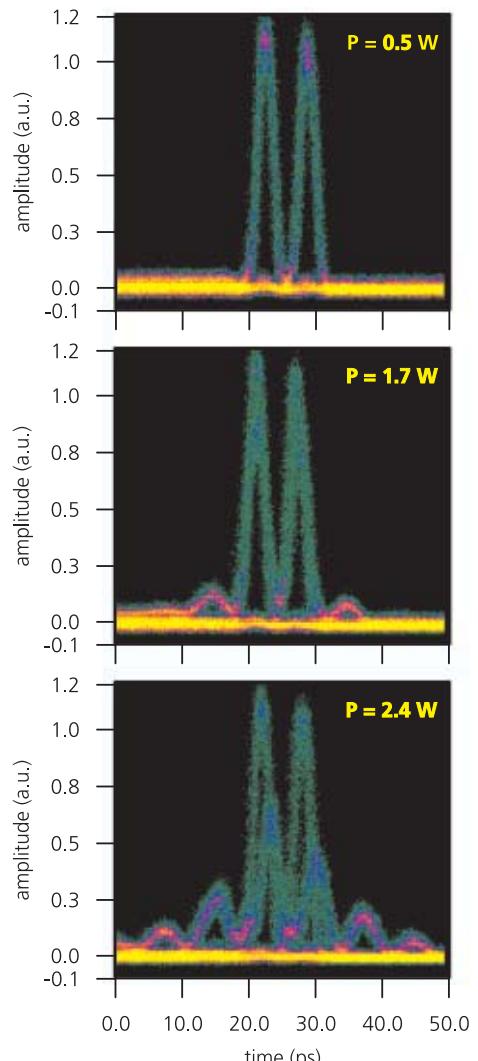


Fig. 2: Measured eye diagrams as a function of the link input power P

simulations confirmed that this asymmetry strongly depends on the relative optical phase of the adjacent 160 Gb/s OTDM-channels.

The development of the all-optical sampling system was supported by the BMBF and the DFG. The presented study is an example of contract research work that HHI conducts for its industrial partners like Alcatel SEL in this case.

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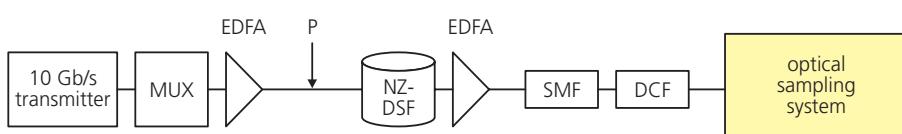


Fig. 1: Experimental set-up for the investigation of IFWM at 160 Gb/s using the optical sampling system

1 C. Schubert et al., OAA 2002, OtuD5

2 C. Schmidt et. al., ECOC 2003, Th2.5.2



HIGH SPEED TRANSMISSION USING DPSK MODULATION FORMAT

The differential phase shift keying (DPSK) modulation format and an ultra-stable clock-recovery improve the 160 Gb/s transmission system of the OTDM group with respect to reliability and transmission distance.

Das Modulationsformat DPSK und eine äußerst stabile Takträckgewinnung verbessern das 160 Gb/s Übertragungssystem der OTDM-Gruppe in Bezug auf Zuverlässigkeit und Übertragungsreichweite.

Internet, video-on-demand and other applications increase significantly the network traffic worldwide. Over large distances, in the so-called backbone network, data are transported using optical fiber networks. The transmission capacity of a single fiber is given by the number of wavelength channels and the bit rate per channel. High data rates per channel are realized using the Time Division Multiplexing (TDM) technique. This is attractive because transmission systems having a small number of wavelength channels (WDM channels) and a high TDM bit rate per channel are expected to be easier to manage and to reduce the cost for equipment. The future TDM bit rate will be 80 or 160 Gb/s. As electrical signal processing at this data rate is not available at present, optical TDM (OTDM) technology is used.

The OTDM-group at HHI was the first to apply the DPSK modulation format to a 160 Gb/s transmission. While in

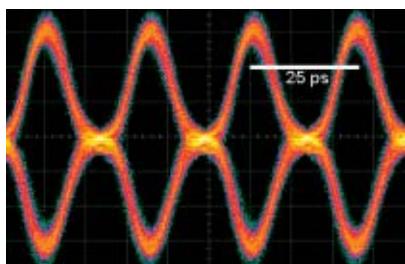


Fig. 1: Eye diagram with DPSK modulation and balanced detection scheme (40 Gb/s detector)



Fig. 2:
Compact
clock-
recovery
module

the traditional modulation format, called On-Off-Keying (OOK) or Amplitude Shift Keying, a '1' is represented by an optical pulse and a '0' by the absence of the pulse, with DPSK modulation the information is coded in a differential way by the change of the optical phase of two adjacent pulses. The DPSK scheme has some advantages. The main advantage is that also a '0' is represented by photons and not just by the lack of photons. The phase change of adjacent pulses is analyzed and transferred to an amplitude modulation using an interferometer in front of the receiver. With a balanced detection scheme the '1's (positive amplitude) and '0's (negative amplitude) are actively detected as can be seen in the eye diagram in Fig. 1 for the received 40 Gb/s signal. Resulting from this bipolar detection scheme, the decision threshold of the receiver is insensitive to signal degradations which is another advantage compared to OOK.

A challenge of high bit rate transmission systems is the so-called clock-recovery (CR), which synchronizes the receiver. Especially for 160 Gb/s transmission, a sub-harmonic clock signal, e.g. at 10 or 40 GHz, has to be extracted for the signal processing. The development of a novel concept¹ was described in detail in the last year's report. A pre-scaled Phase-Locked-Loop (PLL) feedback ensures ultra-stable performance. This patent pending device is now commercially available in a compact box (Fig. 2).

The novel modulation scheme together with the CR enabled new records in 160 Gb/s transmission distance of more than 400 km² and a much higher stability. The transmission

system is now a reliable testbed for further investigations. Fig. 3 shows measured bit-error-ratios after a 240 km transmission analyzing the influence of the input power to each fiber span.³ While high powers cause degradations due to fiber nonlinearities, the performance is limited by the signal-to-noise-ratio when low input powers are used.

For even larger transmission distances, the signal degradation caused by fiber nonlinearity, polarization-mode-dispersion (PMD) and other effects become more and more important. A compensation of these effects or a complete regeneration of the signal is needed at the line-rate of 160 Gb/s which can only be done by all-optical configurations. Different concepts are under investigation and an all-optical 160 Gb/s 3R-regenerator was successfully demonstrated for the first time in collaboration with Fujitsu in Japan.⁴

This leading-edge technology would be impossible without the support of the public institutions, like BMBF and DFG. The transfer to the practical application is greatly driven by the support of our industrial partners worldwide.

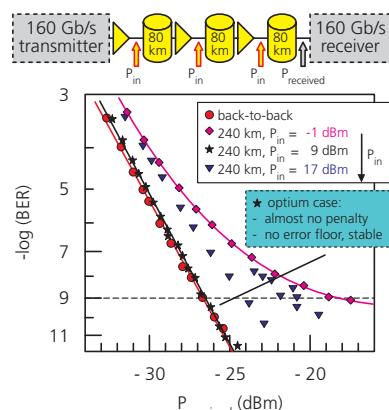


Fig. 3: Setup and bit-error ratios in a 160 Gb/s transmission experiment over 240 km fiber, varying the span input power

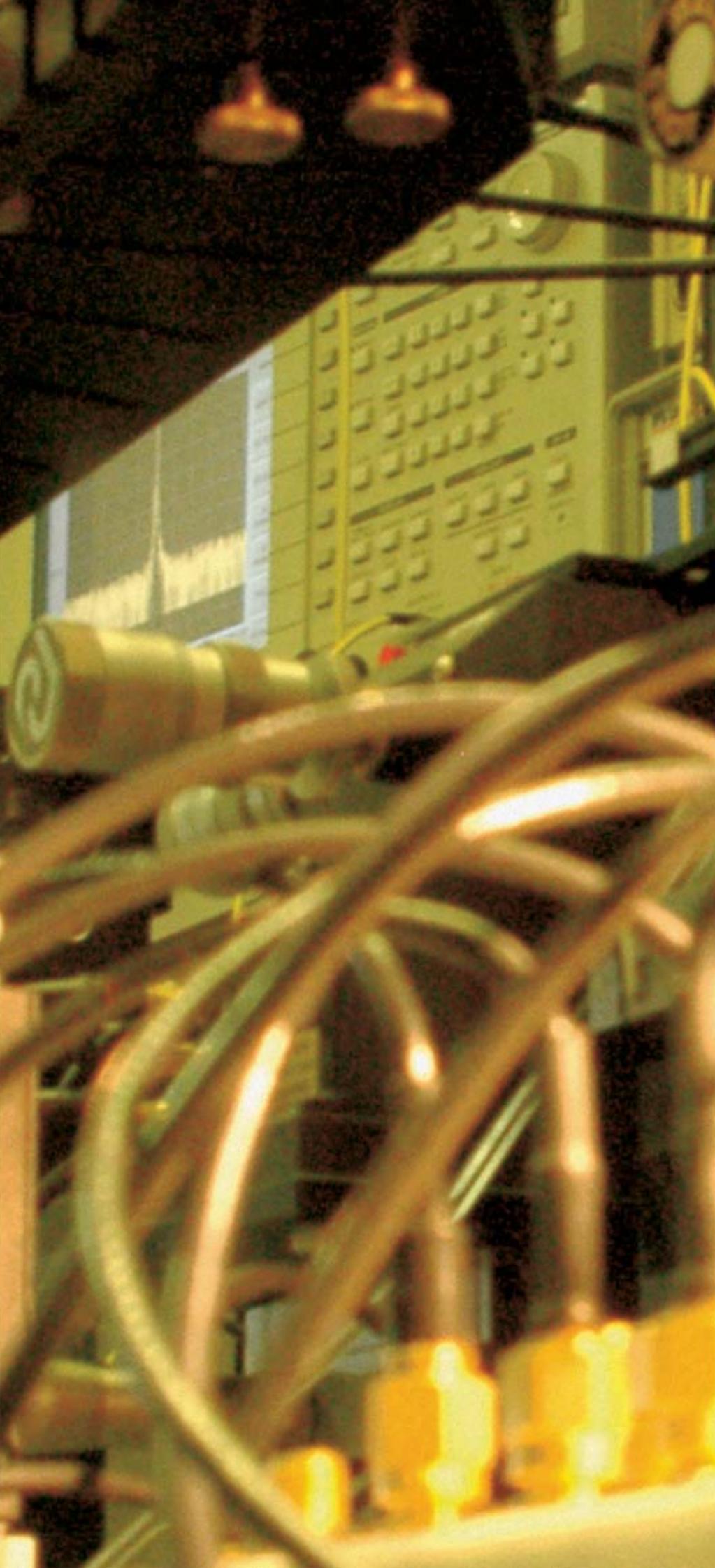
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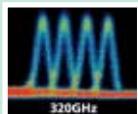
1 Boerner et al., El. Lett 39, 1071 (2003)

2 Ludwig et al., NOC 2003, 14

3 Ferber et al., El. Lett. 39, 1458 (2003)

4 Watanabe et al., OFC 2003, PD16





Photonic Devices

Optoelectronic devices provide key functions to fibre communication systems. The world wide web relies on fibre networks, and also mobile communication would be impossible without a powerful optical network to connect the base stations.

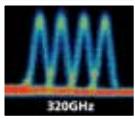
As data traffic continues to double every year one prerequisite for photonic systems is the availability of optoelectronic components with continuously improved characteristics at decreasing cost.

The global trends of R&D in optoelectronic devices are outlined in a number of road maps, which are regularly updated and published e.g. by OITDA (Japan), OIDA (USA) or by European projects such as OPTIMIST. The most relevant developments are aiming at

- 1) improved performance such as higher single channel bit rates (40 Gbit/s ... 160 Gbit/s), modulation formats more complex than simple (N)RZ, and all-optical signal processing comprising optical 3R regeneration, all-optical wavelength conversion and optical switching,
- 2) low(er) cost with particular emphasis on uncooled, directly modulated 10 Gbit/s lasers, hybrid subsystems relying on SiO₂-, SOI- or polymer waveguide-based optical boards, monolithically integrated mode converters for relaxed alignment tolerances, low overall footprint, and low cost devices for wavelength division multiplexing (WDM) applications based on polymer waveguides,
- 3) devices based on advanced concepts such as photonic crystals, which enable extremely compact devices and new functionalities.

Additional market opportunities arise if devices which have been developed for information technology applications can be adapted to the needs of other market segments with minor modifications. One example are semiconductor lasers for analytics and sensing.

At the HHI devices are being developed along the lines outlined above, and the characteristics of such photonic components and subsystems are tested in transmission experiments. Novel concepts and architectures for optical circuits in switching subsystems have been investigated and were successfully validated in system test beds. This is done in cooperation with the systems groups at the HHI as well as in cooperation with industrial partners, ranging from small start-ups to large international companies. The framework of such cooperations are typically national or



European programmes. Selected projects are described in more detail in the following section.

After the downturn in the IT industry many enterprises, start-ups as well as large global companies, have reduced their technological capacities and expenditures significantly, they have transferred production and assembly to low-wage countries or have even become completely 'fabless'. In contrast to these universal trends, the HHI has kept a complete InP technology line including epitaxy, lithography, and planar technology; it possesses all characterisation techniques needed to support device development, and is able to accomplish the packaging of a limited number of modules for systems evaluation. With its R&D work ranging from materials technology to operation and test of modules and subsystems the HHI is unique within Germany and among the other key players in Europe. As a consequence, the HHI maintains a strong position in photonic networks and devices, and it is a competent partner for the industry. The HHI can give efficient support to its partners to establish and maintain leading positions in the market of optoelectronic components and photonic systems, which is currently in a stage of consolidation and slow recovery.

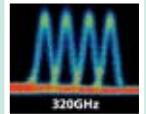
Photonische Komponenten

Optoelektronische Bauelemente in Kombination mit Glasfasern und Mikroelektronik bilden das Rückgrat faser-optischer Kommunikationssysteme, und diese Kommunikationssysteme bilden ein wesentliches Fundament der heutigen in globalem Maßstab eng vernetzten Wirtschaft. Sie sind ebenso die technologische Voraussetzung für das Internet, und auch die Mobilkommunikation wäre ohne ein leistungsfähiges optische Netz im Hintergrund nicht denkbar.

Die zu transportierenden Datenmengen haben seit Jahren hohe Wachstumsraten, und eine wesentliche Voraussetzung dafür, dass immer mehr Daten zu immer niedrigeren Kosten weltweit transportiert werden können, ist die Verfügbarkeit optoelektronischer Bauelemente mit immer weiter verbesserten Leistungsmerkmalen bei gleichzeitig fallenden Bauelement-Kosten.

Bei der Entwicklung optoelektronischer Bauelemente kann man gegenwärtig mehrere Hauptentwicklungstrends beobachten, die u.a. in den road maps von OITDA (Japan), OIDA (USA) und europäischen Projekten (OPTIMIST, ...) publiziert und ständig aktualisiert werden. Diese Trends, an denen sich auch die Bauelement-Entwicklungen am HHI orientieren, lassen sich in drei wesentliche Kategorien einteilen:

- 1) höhere Leistungsfähigkeit:
 - höhere Bitraten im Einzelkanal (40 Gbit/s ... 160 Gbit/s)
 - leistungsfähigere Modulationsformate, die über einfaches (N)RZ hinausgehen
 - rein-optische Signalverarbeitung (3R Regeneration, Wellenlängen-Umsetzung, optisches Schalten)
- 2) niedrige(re) Kosten:
 - Bauelemente, insbesondere Sendelaser für ungekühlten Betrieb und Direktmodulation bis zu 10 Gbit/s
 - hybride Subsysteme auf der Basis von auf SiO₂-, SOI- oder Polymer-Wellenleiter-basierenden optical boards, die für moderate Justagetoleranzen (Feldweitentransformatoren) und möglichst geringe Modulgröße konzipiert sind
 - preisgünstige Komponenten (z.B. WDM-Bauelemente, optische Schalter) auf Polymerbasis
- 3) neuartige Konzepte und Strukturen:
 - Bauelemente auf der Basis photonischer Kristalle, die z.T. extrem kompakte Strukturen oder auch völlig neuartige Funktionalitäten ermöglichen

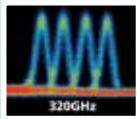


Synergie-Effekte und neue Marktchancen ergeben sich obendrein dadurch, dass für die optische Nachrichtentechnik entwickelte Bauelemente oft auch auf anderen Gebieten eingesetzt werden können, entweder unverändert oder mit geringen Modifikationen (z.B. Halbleiter-Laser, die in der (Gas-) Sensorik eingesetzt werden können, wenn die Emissionswellenlänge sich nicht am ITU-Raster, sondern an den Absorptionslinien des interessierenden Gases orientiert).

Auf allen genannten Sektoren werden am HHI Bauelemente entwickelt und neuartige Bauelement- und Subsystemkonzepte in der Praxis ausprobiert und in Übertragungsexperimenten getestet. Neuartige optische Schaltungsarchitekturen für die Signalregeneration wurden erfolgreich aufgebaut und getestet, z.T. in enger, bilateraler Kooperation mit Industriepartnern, aber auch im Rahmen nationaler oder internationaler (EU-gefördeter) Verbundprojekte. Wegen des begrenzten Raumes kann im folgenden zwar eine repräsentative, aber dennoch unvollständige Beschreibung der aktuellen Komponenten-Entwicklungen gegeben werden.

Nachdem die Euphorie auf dem IT-Markt weitgehend verflogen ist, haben realistische Kosten- und Gewinnabschätzungen viele Firmen dazu veranlasst, – angefangen von den start-ups bis zu den großen ‚global players‘ – ihre Technologie-Kapazitäten zum Teil drastisch zu reduzieren, zu verlagern oder sogar vollkommen ‚fabless‘ zu werden. Das HHI verfügt nach wie vor über eine komplette InP-Technologie-Linie, angefangen von der Epitaxie über die planare Prozessierung, stets begleitet von einer umfangreichen Messtechnik, bis zum Aufbau einer begrenzten Anzahl von Modulen für System-Tests innerhalb und außerhalb des Hauses.

Das Zusammenspiel zwischen Systemarbeiten, Komponentenentwicklung und permanenter Verbesserung der Materialtechnologie ist einzigartig in Deutschland und führend in Europa. Dies stellt den Schlüssel für erfolgreiche Arbeiten auf dem schwierigen Markt und dem schnell veränderlichen Forschungsgebiet der Photonischen Netze und Komponenten dar. Das HHI ist damit vor allem für start-ups (weiterhin) ein wichtiger, verlässlicher und leistungsfähiger Partner, der es den kooperierenden Firmen ermöglicht, weltweit Spitzenpositionen zu erwerben bzw. zu verteilen.



PHOTONIC DEVICES

Photonic Devices

Optical Signal Processing

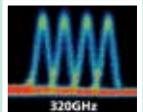
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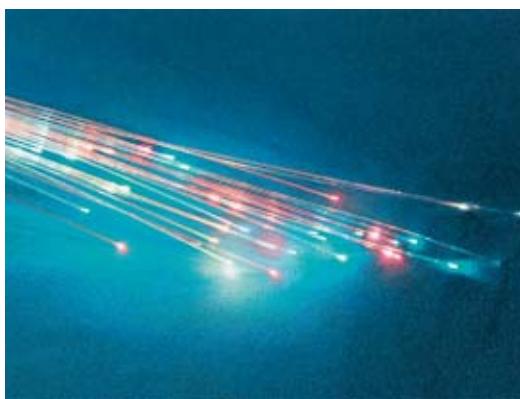
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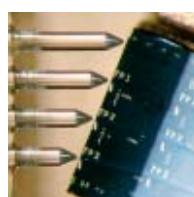


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High Bitrate Modulators	Karl-Otto Velthaus	Phone e-mail	-645 velthaus@hhi.fhg.de



Measurement setup for characterization of special laser diodes



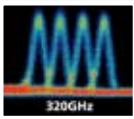
Coupling of fiber-array to MZI-SOA ultra-fast optical switch (DEMUX 160 Gb/s to 10 Gb/s)



Continuously variable delay line for optical signal processing (loss variation < 0,2 dB)



Low foot-print, packaged selfpulsating laser for clock extraction at 40 Gb/s



UNCOOLED 10 GBIT/S LASER DIODES

1310 nm Fabry-Perot type InGaAlAs/InP ridge waveguide laser diodes have been developed for 10 Gbit/s transmission and +85°C uncooled operation in metropolitan and access networks. The chip design allows for flip-chip mounting.

1310 nm InGaAlAs/InP Fabry-Perot Laser wurden für den Einsatz in Metro- und Access-Netzen entwickelt. Die Laser sind für Übertragungsraten von 10 Gbit/s und ungekühlt bis +85 °C einsetzbar und sind für Flip-chip-Montage vorbereitet.

Optical transceivers for 10 Gbit/s transmission ('10 G ethernet') are in the components focus for fiber based optical metropolitan and access networks. As major requirements, such transceivers, which basically comprise transmit and receive and electrical multiplexing functions, have to comply with small-form-factor module standards, have an electrical power budget as low as possible, and have to meet the operating specifications over the full temperature range from 0 – 85 °C. For cost reasons this has to be accomplished without any active cooling.

These issues translate into challenging demands on the laser diode, one of the crucial devices in optical transceivers: low threshold current; high output power efficiency; specific spectral properties; cut-off frequency > 10 GHz at operating currents as low as possible; temperature stability; guaranteed lifetime, and others. Generally, the laser devices that are commercially available today do not yet satisfactorily meet this bundle of key requirements. Regarding the wavelength these laser diodes are predominantly designed for the low-dispersion 1300 nm transmission window. This is because the bulk of the

optical links in the metro- and access area covers distances below 2 km allowing multimode Fabry-Perot lasers to be employed.

Buried heterostructure (BH) laser diodes made of InGaAsP/InP to a great deal fulfill the requirements for uncooled 10 Gbit/s lasers. However, due to inherent band structure properties InP based lasers with active InGaAsP layers behave rather temperature sensitive, particularly at temperatures above some 60 °C. In this respect the use of InGaAlAs as active QW material is known to lead to superior laser performance.

Since the fabrication of Al containing BH lasers is still a major technological challenge a RW structure has been adopted for the InGaAlAs/InP laser devices developed in the reporting year. For these devices a complex epitaxial structure has been developed comprising some 30 different layers.

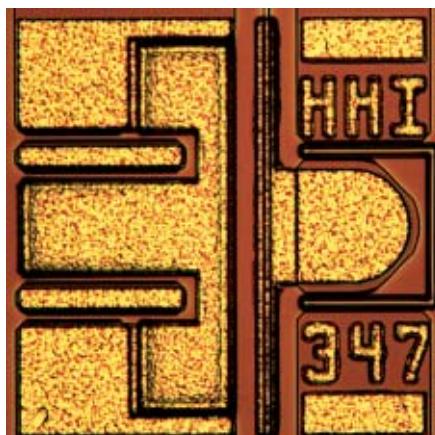


Fig. 1: RW-laser chip with top-side p- and n-electrodes as required for flip-chip mounting

The laser chips are uniquely designed such that the n-contact is formed on both the back side and the top side to optionally allow for flip-chip mounting. No significant difference in the series resistance was found for these two alternative contact schemes. In contrast to InGaAsP/InP lasers the InGaAlAs/InP devices require the mirror facets to be coated for enabling reliable operation. These coating layers made of TiO₂/SiO₂ are concurrently

used to modify the optical mirror reflectivities.

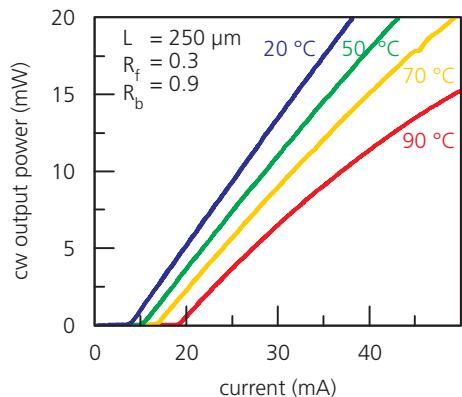


Fig. 2: Temperature dependent P-I characteristics of an 1310 nm InGaAlAs-RW laser

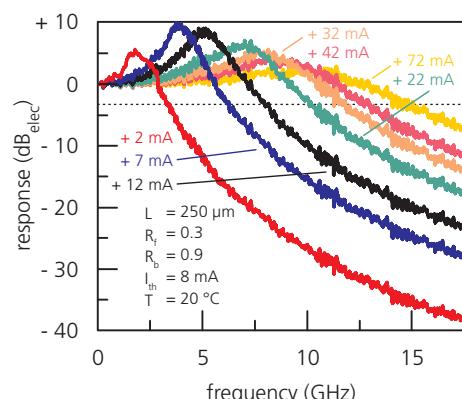
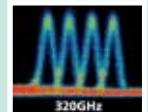


Fig. 3: Frequency response under small-signal modulation

Figs. 2 and 3 show typical results for lasers with 250 µm cavity length and 30/90% mirror reflectivities. Threshold currents are well below 10 mA and 20 mA at room temperature and 90 °C, respectively, resulting in a T₀ – value of about 85 K over this temperature range. The 3 dB cut-off frequency exceeds 10 GHz at bias currents of around 20 mA.

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1.55 µm DFB LASER WITH INTEGRATED SPOT-SIZE-CONVERTER FOR FLIP-CHIP-APPLICATIONS

Directly modulated Distributed Feedback (DFB) lasers for 10 Gbit/s applications are of major interest e.g. for application in CWDM (= Coarse Wavelength Division Multiplexing) MAN (Metropolitan Area Network) systems. We developed flip-chip adapted 1.55 µm DFB laser devices which are indispensable for cost efficient optical board assembly.

Direkt-modulierbare Distributed Feedback- (DFB) Laser für Übertragungsraten von 10 Gbit/s sind für zahlreiche Applikationen von großem Interesse, insbesondere auch für CWDM- (= Coarse Wavelength Division Multiplexing) MAN- (Metropolitan Area Network) Systeme. Wir entwickelten Flip-Chip-adaptierte 1,55 µm DFB-Laser für eine kosteneffiziente „Optical-Board“-Montage.

We developed a directly modulated 1.55 µm buried heterostructure DFB laser diode consisting of a 300 µm $\lambda/4$ phase shifted DFB section and a separate 200 µm spot size converter region (Fig. 1). The device has the potential for cost efficient passive aligning flip-chip set-up.

Investigations were performed on devices with active and passive ITG (= Integrated Twin Guide) coupled laterally tapered spot size transformer sections. The active taper section is designed with an angled output facet (7°) in order to reduce disturbing back reflections. In the passive taper section the upper laser waveguide and the multi-quantum active layers were removed and only the lower transparent laser waveguide remains. For the active taper where the laser structure is extended into the taper section current injection is performed via

electrical contacts to regulate the absorption or the amplification in the taper region.

Characteristics of such flip-chip adapted laser diodes are:¹

- single mode power output in the range of mWs (Fig. 2),
- low sensitivity to back-reflections from the board interface,
- large alignment tolerances for reliable single mode optical interfacing,
- cost efficient passive self-alignment via multiple solder bumps and integrated alignment stops.

The near-field of the taper end is optimised for butt-coupling to single-mode SOI (Silicon on Insulator) board-waveguides or a single mode fibre with dimensions of a few microns. The measured corresponding far-field angles of the untapered back facet and tapered angled front facet are shown in Fig. 3.

The advantages of the passive taper version are a narrower far-field, no additional taper driving current, and a more simple board waveguide or fibre alignment. The bent active taper type exhibits larger output power and a lower feedback sensitivity. Both devices are capable for cost efficient laser module fabrication by using passive self alignment flip-chip mounting technology.

The work was supported by the Federal Ministry of Education and Research under grant 01 BP 281.

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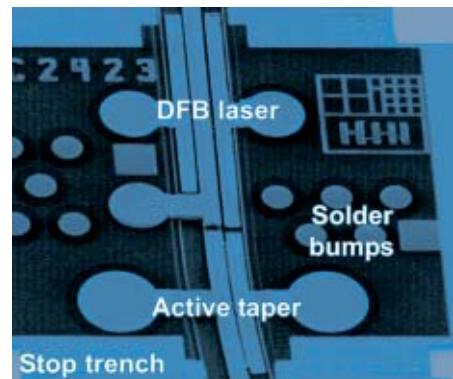


Fig. 1. DFB-laser with active bent taper section

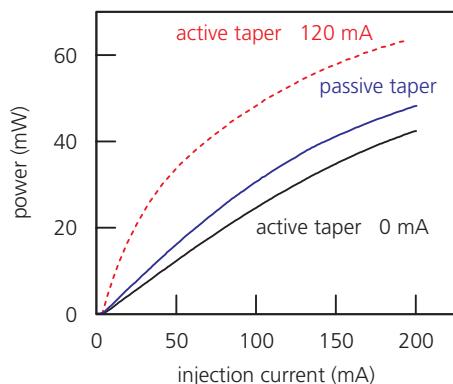


Fig. 2. Output power of laser devices with integrated field transformers: active and passive taper section

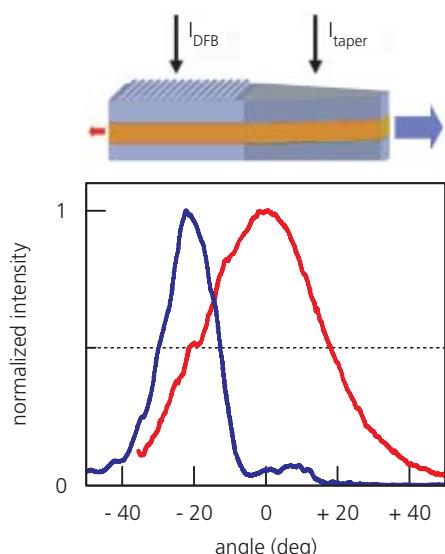
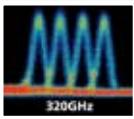


Fig. 3. Schematic set-up of an all-active laser with integrated field transformer (here shown with straight taper section) and far-field characteristics of untapered back side facet (red) and active bent tapered front facet (blue)

¹ K. Janiak, J. Kreissl, S. Fidorra, T. Hartwich, W. Rehbein and H. Heidrich: "1.55 µm BH-DFB laser with integrated spot-size-converter for flip-chip-applications", Proceed. IPRM 2004, Kagoshima (J), May 31 – June 4, 2004



COMPACT 40 GHZ PULSE LASER MODULES WITH INTEGRATED MONOLITHIC MODE-LOCKED SEMICONDUCTOR LASER

Monolithically integrated mode-locked 40 GHz SIPBH lasers on GaInAsP/InP have been developed and fabricated (SIPBH: Semi-Insulating Planar Buried Heterostructure).¹ First selected laser chips with a footprint of only 0.3 mm² were packaged into compact, fibre pigtailed pulse laser modules. The functionality of these modules was experimentally demonstrated in system experiments and on an industrial exhibition at the Optical Fiber Communication Conference (OFC'2003) in Atlanta/USA.

Monolithisch integrierte, moden-gekoppelte 40 GHz SIPBH Laser-pulsquellen wurden, basierend auf dem Halbleiter-Materialsystem GaInAsP/InP, entwickelt und hergestellt.¹ Erste, vereinzelte Laserchips, deren gesamter Flächenbedarf lediglich 0,3 mm² beträgt, wurden zu einsetzbaren Pulslasermodulen mit Glasfaseranschluss aufgebaut. Die Funktionalität dieser Module konnte in Systemexperimenten getestet und auf einer Industrieausstellung während der Optical Fiber Communication Conference (OFC'2003) in Atlanta/ USA experimentell demonstriert werden.



Fig. 1. Photo of a compact 40 GHz pulse laser module integrating a monolithic mode-locked laser mounted on a line-card (optical output with connected fibre on the left, electrical high frequency input port on the right, module fabrication: u2t Photonics AG, Berlin)

The integrated monolithic mode-locked laser was fabricated at FhG-HHI. The chip packaging into compact pulse laser modules was accomplished by the industrial partner u2t Photonics AG Berlin. A photograph of a fibre pigtailed 40 GHz module is shown in Fig. 1 and a compilation of the most relevant performance data, achieved at different modules to date, is given in Tab. 1 (cf. also Fig. 3). The large repetition rate tuning ranges in Tab. 1 are achievable by changing only the bias conditions in the gain and saturable absorber sections. No other tuning elements have to be biased (e.g. phase tuning sections). The result of a first bit-error rate measurement is shown in Fig. 3.

Repetition rate	38.0 ± 0.4 GHz
Repetition rate tuning	200 ... 380 MHz
Pulse width	2.0 ... 2.8 ps
Time-bandwidth product	0.33 ... 0.55
Optical power in fibre	0.3 ... 1.5 mW
Center emission wavelength	1536 ± 3 nm
Timing jitter *)	160 ... 280 fs
Amplitude noise	4 ... 9 %
Ext. RF power	18 ... 24 dBm

Tab. 1: Compilation of different performance data for hybrid mode-locking [1], taken from measurements on first compact 40 GHz pulse laser modules incorporating a monolithic mode-locked laser [*] 100 Hz ... 10 MHz offset from subcarrier].

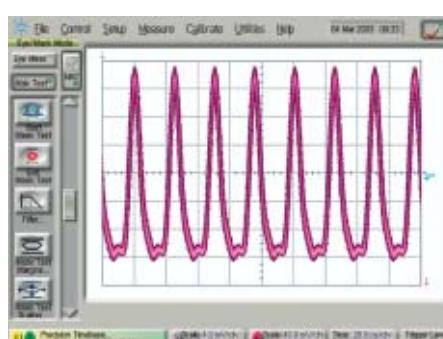


Fig. 2: Trace of 40 GHz optical pulses from a fibre pigtailed pulse laser module

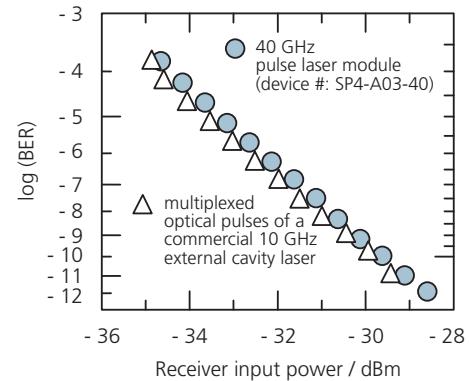


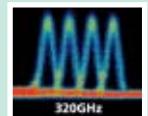
Fig. 3: Bit-error rate (BER) performance of a 40 GHz pulse laser module in comparison with a hybrid transmitter consisting of a commercially available 10 GHz external cavity pulse laser and a multiplexer for 40 GHz signal generation (back-to-back measurement)

All performance characteristics achieved to date are already very promising. However, further research and development activities are required to make future commercial applications of these compact pulse lasers possible (e.g. in advanced high capacity optical communication systems, within optical interconnects of next computer generations, in high-speed optical sampling systems, or for the characterization of fast physical processes or high speed optoelectronic devices).

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

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1 R. Kaiser, B. Hüttl, H. Heidrich, S. Fidorra, W. Rehbein, H. Stolpe, H. Stenzel, W. Ebert, G. Sahin; "Tunable mode-locked lasers on InP with low timing jitter", IEEE Photon. Technol. Lett., Vol. 15, no. 5, pp. 634-636, 2003.



SELPULSATING LASERS AS PULSE SOURCE FOR RZ MODULATION FORMAT

The scheme of a compact and cost efficient 40 Gbit/s transmitter for RZ transmission format has been developed. The key device is a pulse source based on selfpulsating lasers. The transmitter performance is evaluated in a data transmission experiment over 80 km standard fibre. The bit error ratio is recorded after dispersion compensation. An error free transmission is demonstrated.

Ein neues Design für einen kompakten und kostengünstigen 40 Gbit/s Sender für das RZ Übertragungsformat wurde entwickelt. Die Schlüsselkomponente des Senders ist eine Pulsquelle, die auf selbstpulsierenden Lasern basiert. Die Funktionalität des Senders ist in einem Übertragungsexperiment über 80 km Standardfaser getestet worden. Die Bitfehlerrate wird nach Dispersionskompensation aufgenommen und eine fehlerfreie Übertragung wird erreicht.

Next generation of optical transmission systems will operate at speed of 40 Gbit/s. Return to zero (RZ) transmission format leads to higher receiver sensitivity which in turn allows for higher system margins. The scheme of a conventional RZ transmitter is shown in Fig. 1. The required optical components are a continuous wave (CW) laser and two modulators, each followed by an optical amplifier to compensate for the losses. The first modulator, driven by an electrically amplified

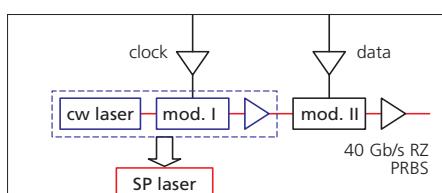


Fig. 1: Scheme of a conventional transmitter. In our approach three components (blue plotted devices) are replaced by a selfpulsating laser

sinus clock signal, is used to create the pulse train. The second modulator, driven by the electrically amplified signal pattern, encodes the data information.

In our approach we replace the CW laser, the first modulator and the first optical amplifier by only one optical device, the selfpulsating PhaseCOMB laser (**Phase Controlled Mode Beating**).¹ The benefits of the new transmitter design are compactness and lower costs.

The self-pulsating laserchip is based on a 1.5 μ m InGaAsP-InP ridge-waveguide structure. It is developed and processed in HHI. The laser is packaged into a surface mountable butterfly module by u2t Photonics a spin-off company of HHI. A photograph of the pigtailed module is shown in Fig. 2. The laser module can be operated at various data rates, e.g. 40 or 43 GHz.



Fig. 2: Photo of the 40 GHz pulse source module

Latter is applied for transmission with forward error correction (FEC). The pulse trace emitted from the electrically synchronized module is shown in Fig. 3. A sinusoidal shaped, sharp signal trace can be observed. The timing jitter of the trace, measured by the scope, is less than 400 fs. The extinction ratio is up to 10 dB and the power coupled into the fibre is about 0 dBm. The optical spectrum consists of two laser modes with a distance of 40 GHz. The device can be fabricated for any standardised wavelength.

In order to evaluate the performance of our transmitter a 40 Gbit/s RZ signal was send over 80 km standard single mode fibre. The dispersion was compensated after transmission.

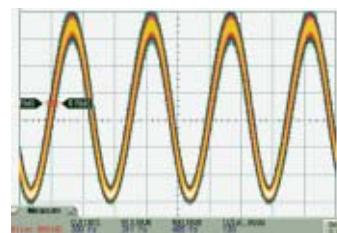


Fig. 3: Pulse trace of the electrically synchronized PhaseCOMB Laser at 40 GHz. Jitter is below 400 fs

The bit error ratio (BER) recorded back to back and after transmission is shown in Fig. 4. Error free operation ($BER < 10^{-11}$) without any indication of an error floor is obtained, and no receiver sensitivity penalty compared with the back to back case can be observed.

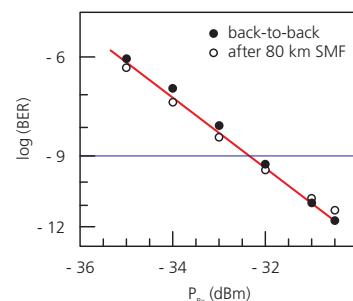


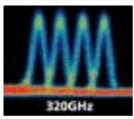
Fig. 4: BER recorded back to back and after transmission over 80 km SMF. Error free transmission with $BER < 10^{-11}$ is achieved

Our transmitter concept is a cost-saving solution since three optical components -laser, modulator and amplifier- are replaced by one device -the selfpulsating laser. The BER recorded after transmission demonstrates the high performance of the 40 GHz pulse source. The work on reliability of wafer processing and performance of the pulse source will be continued to allow for commercial application in collaboration with our partner u2t Photonics, Berlin.

We thank the German Federal Ministry of Education and Research for financial support.

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¹ C.Bobbert et al. "Compact 40 GHz RZ-transmitter design applying self-pulsating lasers", Electronic Letters 40, pp 134-5 (2004)



ALL-OPTICAL CLOCK – A KEY DEVICE FOR PHOTONIC NETWORKS

All-optical clock recovery is a key function for optical signal processing in global high-speed networks. The FhG-HHI has developed and manufactured an all-optical clock based on self-pulsating DFB lasers. These devices combine compact size and simple operation with excellent system performance and high speed potential up to 160 Gbit/s. Now the FhG-HHI offers first clock modules for industrial and research partners.

Am FhG-HHI wurden rein-optische Taktregeneratoren auf der Basis selbst-pulsierender DFB Laser entwickelt. Diese Bauelemente kombinieren eine kompakte Bauform und einfachen Gleichstrom-Betrieb mit einer sehr guten System-Performance und einem hohen Geschwindigkeits-Potential bis zu 160 Gbit/s. Das FhG-HHI stellt jetzt erste Clock-Demonstratoren den Industrie- und Forschungspartnern zur Verfügung.

The operation scheme of the all-optical clock is depicted in Fig. 1. The device is 800 µm long and comprises two DFB lasers and an integrated phase tuning section. The self-pulsating laser (SP-laser) operates at high frequencies due to the properly designed DFB gratings. The pulsation frequency can be tuned continuously in a wide range (25 GHz–50 GHz) via the three driving direct currents. The SP-laser synchronizes to the injected PRBS data signal and emits a sinusoidal pulse trace. The recovered clock

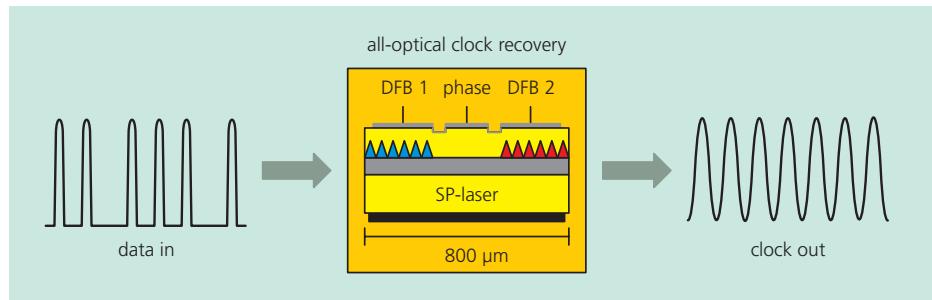


Fig. 1: Operation scheme of the self-pulsating laser for clock recovery

signal is stable in amplitude and time even for strongly degraded signals (Fig. 2). Thus the self-pulsating laser matches the demands for all-optical 3R signal regeneration (Re-amplification, Re-timing, Re-shaping). In this case a high precision time base is required. The clock has shown excellent system performance in several 3R regenerator concepts and loop experiments at 10 Gbit/s and 40 Gbit/s.

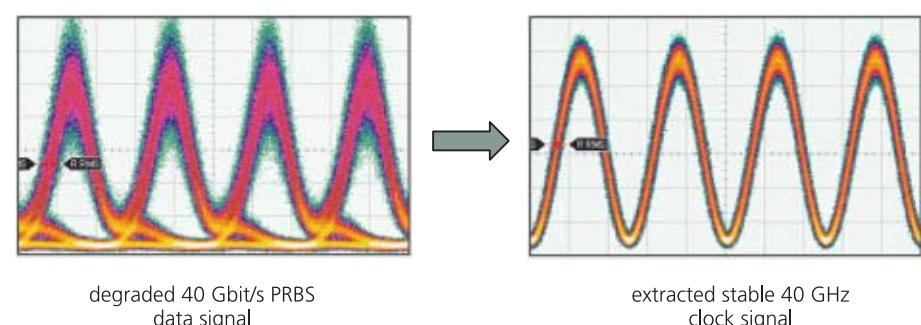


Fig. 2: Impact of the data degradation on the optical clock stability

one. The all-optical clock recovery doesn't need an opto-electronic conversion, thus expensive electronic components can be avoided. In addition the same self-pulsating laser can be used for different bit rates (e. g. FEC or super FEC). Beyond 40 Gbit/s electronics is limited by the bandwidth. The all-optical clock with its speed potential up to 160 GHz overcomes this drawback and allows to

In future optically switched flexible networks asynchronous packets and burst data sequences have to be processed. The ultra-fast locking of the all-optical clock within a few ns to a packed header makes it very attractive for these applications.

Comparing an optical clock recovery to electronic circuits there are some important advantages for the optical

upgrade the networks to higher data rates.

Moreover the self-pulsating laser covers a wide range of different applications. Future monolithic or hybrid integration of the SP-lasers into photonic circuits will pave the way for optical signal processing in global optical networks.

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Advantages of the optical clock:

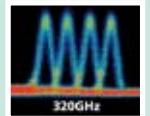
- no o/e conversion: all-optical
- no rf electronics: dc supply
- bit-rate flexible: 25–50 GHz
- ultra-fast locking time: < 3 ns
- high speed potential: 40–80–160 GHz



Fig. 3: Key characteristics of the optical clock

Applications of the optical clock:

- high speed all-optical networks
- burst / packet switched networks
- time base for opt. signal processing
- all-optical 3R signal regeneration
- all-optical demultiplexing



SEMICONDUCTOR OPTICAL AMPLIFIER AS FAST OPTICAL SWITCH AND ITS APPLICATION

Semiconductor optical amplifiers are universal components both for linear and nonlinear applications in optical communications.

Components are developed and applied at HHI.

Optische Halbleiterverstärker sind universelle Bauelemente sowohl für lineare als auch für nichtlineare Anwendungen in der optischen Nachrichtentechnik. Am HHI werden diese Komponenten entwickelt und eingesetzt.

The semiconductor optical amplifiers (SOAs) are one of the important elements in optical communication technologies. SOAs are simple and ubiquitous optical gain blocks. They are small of size and cheap. A broad optical bandwidth (1200 nm – 1650 nm) can be covered by using a different material composition of the active gain medium. Additionally, the integrability makes the SOAs attractive regarding compact building blocks for system applications.

SOAs can be used in linear and nonlinear regime. Some of the linear applications of the SOAs are optical packet switching, modulation, in-line amplification for dense/coarse wavelength division multiplexing systems and amplification for dynamic networks. Typical lengths of the linear SOAs are 300 µm to 1000 µm.

Nonlinearities in the SOA caused by free-carrier dependent effects have a time constant of about 100 ps. Other effects such as carrier heating/cooling and spectral hole burning have shorter time constants. The bound electrons contribute to higher order nonlinearities such as Kerr effect and four-wave mixing. Nonlinearities are used for different high-speed all-optical signal processing applications at HHI: wave-



Fig. 1: Photograph of the monolithically integrated SOA based Mach-Zehnder interferometer

length conversion, demultiplexing for optical time division multiplexing¹, optical regeneration², logic gating and optically controlled switching. Typical SOA lengths are 1000 µm to 2000 µm. The developed monolithically integrated SOA based Mach-Zehnder interferometers (MZIs) (Fig. 1) have been successfully used for ultrafast all-optical switching applications (Fig. 2) within the "Alcatel Research Partnership Program".

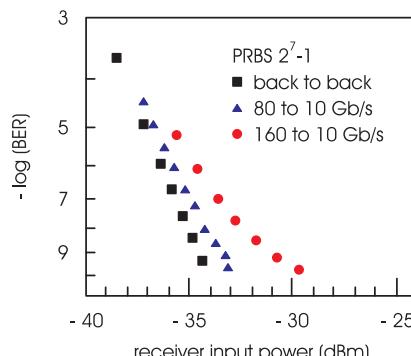


Fig. 2: Bit-error ratios for 80 to 10 Gb/s and 160 to 10 Gb/s all-optical demultiplexing by using the SOA based MZI¹

Recently, a novel SOA structure³ (Fig. 3) has been developed at HHI within the BMBF funded project, ASYNREG. This

novel SOA module (Fig. 4) with its ultralong active gain medium (> 4 mm) opened new perspectives in the realization of semiconductor based compact true all-optical 3R regenerators (re-amplification, re-timing, re-shaping) and wavelength conversion.

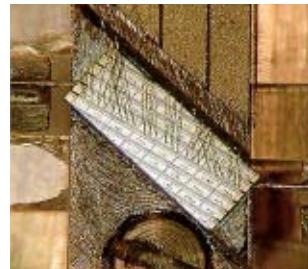


Fig. 3:
Photograph
of ultralong
SOA chip

The development of SOA components is based on 20 years experience in high performance technology, device prototyping and system tests. HHIs leading-edge technology with its special SOAs is available for system tests and also for customized applications.

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1 Tekin et al., IPR 2002, IWC4.

2 Tekin et al., ECOC 2003, We4P119.

3 Busolt et al., ECOC 2003, Th3.5.1.

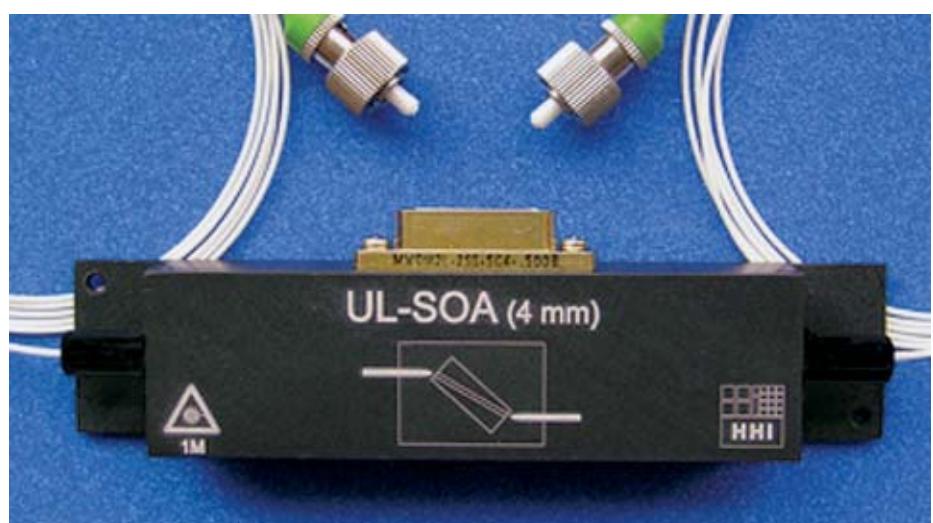
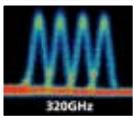


Fig. 4: Photograph of the packaged ultralong SOA



HIGH-BIT RATE MACH-ZEHNDER MODULATORS

A Mach-Zehnder-Modulator (MZM) based on InP and integrated with an optical spot size converter (SSC) features 30 nm optical bandwidth, low-chirp, low driving voltage, small footprint and stable operation over time (Fig. 1). It shows high bit rates, far exceeding 40 Gbit/s approaching 100 Gbit/s in the near future. A hybrid and later on a possibly full integration of the driver-IC will lead to cheap and stable modulator-modules.

Moreover with its MZM-design the modulator is suited not only for standard on-off-keying modulation, but also for enhanced new modulation schemes like Carrier Suppressed RZ (CS-RZ) or Differential Phase Shift Keying (DPSK).

Der auf InP basierende Mach-Zehnder Modulator mit integriertem optischem „spot size converter“ zeigt herausragende Produktionsdaten, wie z.B. eine optische Bandbreite von 30 nm, geringen Chirp und kleine Abmessungen. Er benötigt geringe Treiberspannungen und zeigt Übertragungsraten weit über 40 Gbit/s. In naher Zukunft sollen 80–100 Gbit/s erreicht werden. Aufgrund seines Designs ist der Modulator nicht nur für die aktuellen Standardmodulationsverfahren, sondern auch für zukünftige Phasenmodulationsverfahren wie CS-RZ oder DPSK gerüstet.



Fig. 1: Packaged MZ-Modulator for 40 Gbit/s

To achieve the high data rates, the modulator features a travelling wave electrode (TWE) (Fig. 2). One can see the two TWE electrodes which are designed as microstrip lines, where the overall impedance can be matched to 50Ω by the capacitive load of the distributed electrodes on the MZ arms.

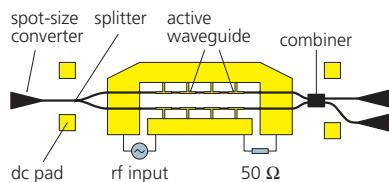


Fig. 2: Schematic layout of a MZI based modulator with capacitively loaded travelling wave electrodes

The modulator operates in a balanced push-pull configuration for low-chirp operation. The cross section of an MZI sector is shown in Fig. 3. The layers with various material sequences are indicated schematically. The reverse biased pn-junction of the MZI is shown as the capacitive load of the TW-electrode.

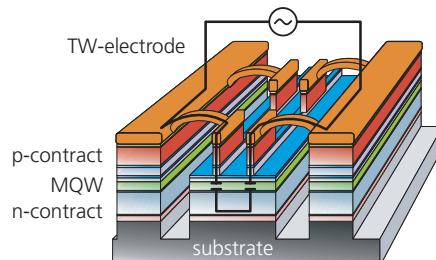


Fig. 3: Cross sectional view of a MZI sector with capacitively loaded TWE's via air-bridge contacts

The electro-optical response of this device is shown in Fig. 4.

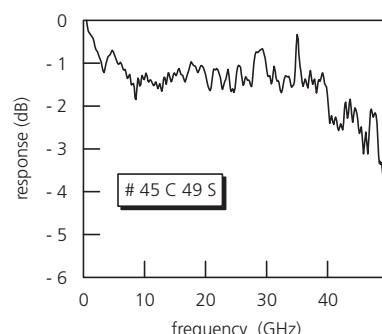


Fig. 4: Electro-optical response measured by a fast photo diode

The optical output signal is transferred to the electrical domain using a high

speed photodiode ($u2t$) and is measured with an electrical spectrum analyser. The 3dB bandwidth exceeds 45 GHz which is the limit of the actual measuring setup.

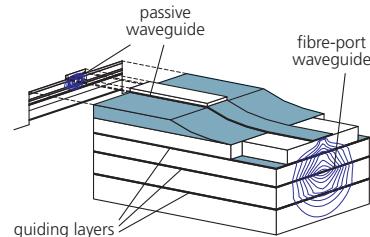


Fig. 5: Layout of the spot size converter; field distribution for the fundamental mode in the passive and fibre port waveguide, respectively

The optical design of this modulator includes a vertical spot-size-converter for coupling to cleaved fibres with low insertion loss. The layout of this crucial system part is shown in Fig. 5. The successful function of the SSC is shown by the improved alignment tolerances and a measured improvement in the insertion loss of 4 dB compared to coupling with tapered fibres.

A packaged modulator for 40 Gbit/s is shown in Fig. 1. Actual developments include a hybrid integration of the modulator together with the driver electronics (Fig. 6). This will be the basis of improved modulator designs that could achieve transmission rates up to 160 Gbit/s.

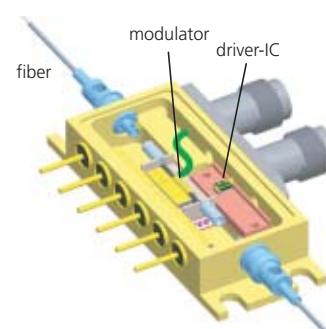
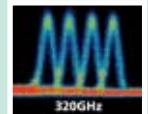


Fig. 6: Modulator-module with hybrid integrated driver-IC

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



LIGHT SOURCES FOR OPTICAL SENSOR APPLICATIONS

Optical sensor applications often require tailored light sources. Our involvement in the development of innovative sensing equipment is demonstrated through DFB lasers for gas sensing and a novel light source module for optical computer tomography (OCT) applications.

Optische Messanalytik ist ein relativ junger Anwendungsbereich für maßgeschneiderte Lichtquellen. Unsere Untersuchungen werden durch DFB Laser für die Gasanalyse und durch ein neuartiges Lichtquellenmodul für Anwendungen in der optischen Computer-Tomographie (OCT) demonstriert.

The development of novel InP based optoelectronic semiconductor devices was mainly driven by the evolution of the optical communication systems. However, in the past few years, further application fields for related devices have appeared.

HHI in collaboration with R&D teams of various manufacturers of sensing equipment is intensively engaged in this evolution.

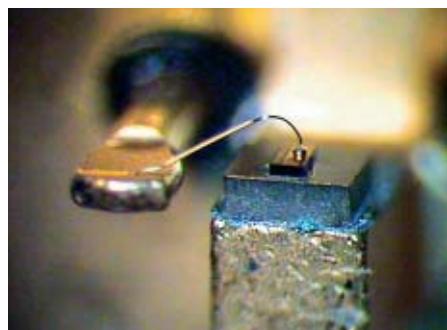


Fig. 1: DFB Laser mounted on a SOT-type header

DFB Lasers, tailored to specific wavelengths, are crucial devices for applications as gas sensing, pollution control, process control involving gaseous reactions etc. Our lasers, featuring specific wavelengths in the 1250–1750 nm range with ± 1 nm accuracy

are provided either as chips-on-header (Fig. 1), or as miniature self-supported TE-cooled modules (Fig. 2).



Fig. 2: DFB Laser mounted on a compact TO8 module with integrated TE cooler

These lasers are part of the SPECDILAS® laser series distributed by Laser Components GmbH (www.lasercomponents.de). Their success can be mainly credited to the high reliability obtained, as well as the versatile choice of headers and on-demand module fabrication.

Another example of a successful involvement to the development of new sensing systems is the design and fabrication of a novel light source for OCT applications. In this case a “turnkey” approach was preferred, encompassing the development of a specific module, involving 8 light channels and the corresponding power and temperature control (Fig. 3).

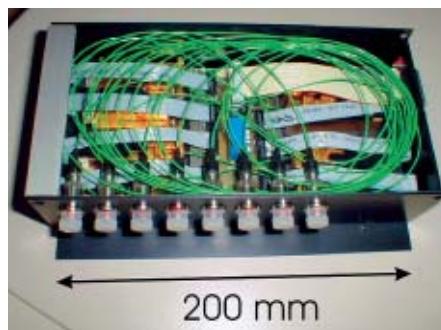


Fig. 3: 8-channel compact light source module developed for OCT applications

These modules were delivered to an industrial partner, ISIS Optronics GmbH of Mannheim (www.isis-optronics.de) and were successfully integrated into their newly developed SkinDex 300 system. A microscopic view in skin or tissue until 1 mm

penetration depth can be conducted by this method. This optical research scanner offers significant advantages as compared to other non-invasive methods, like ultrasound imaging or confocal microscopy:

- Larger penetration depth as compared to confocal microscopy
- Significantly better spatial resolution than ultrasound imaging
- Morphologically similar information content as histological slides
- Choice of the contact medium is non-critical

Using the ISIS technology, 2-dimensional (2-D) images are of similar quality as compared to histological slides. The spatial resolution in lateral and depth direction is on the order of a few μm . Larger cells and the stratum corneum in the lower arm for example are well resolvable.

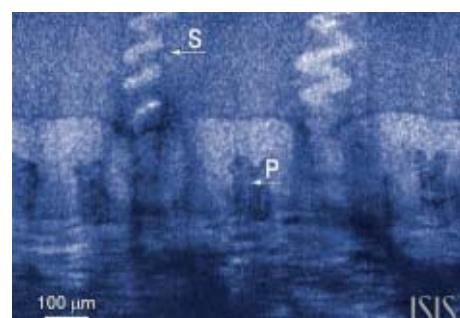
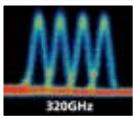


Fig. 4: Palm of hand image provided through OCT. The dark band of the stratum corneum is disrupted by 2 spiralled sweat gland ducts (S). Within the epidermal/dermal junction papillary structures (P) are visible

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40 GBIT/S BALANCED PHOTORECEIVERS – COMPONENTS FOR THE DATA TRAFFIC ON THE EXPRESS LANE

We continuously develop and improve a family of ultrafast photodetectors and photoreceivers for fiber-optic communications in the 10-40-80-160 Gbit/s data ranges according to industry specifications. A new-comer in this receiver family is a novel balanced photoreceiver for 40/43 Gbit/s data rates.

Wir arbeiten kontinuierlich an der Weiterentwicklung einer Familie ultraschneller Photo-Detektoren und -Empfänger für Datenraten von 10-40-80-160 Gbit/s gemäß Spezifikationen unserer Industriepartner. Ein neues Mitglied dieser Photoempfängerfamilie ist ein neuartiger sogenannter Balanced Photoempfänger für 40/43 Gbit/s Datenraten.

Balanced photoreceivers gain growing attraction for system designers due to the potential of an improved receiving sensitivity in long haul fibre links utilizing DPSK modulation formats and balanced detection. We present for the first time a monolithic integration of an amplified balanced photoreceiver OEIC, based on InP, comprising two waveguide-integrated photodiodes and a broadband distributed amplifier. The integration of the distributed amplifier provides about 12 dB of additional power gain and ensures a low output reflection, guaranteeing a good signal integrity in conjunction with subsequent electronics.

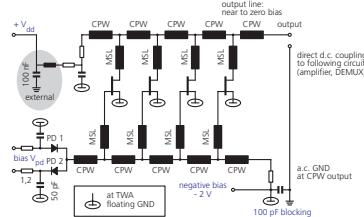


Fig. 1: Schematic of a balanced receiver showing two photodiode inputs (PD1, PD2), the distributed amplifier, and the biasing network, see Fig. 4.

Fig. 1 depicts the circuit diagram of the balanced receiver, a microscope view of the finished chip is given in Fig. 2. It is integrated by a two-step epitaxy process using MOVPE as well as MBE and by applying MMIC techniques.¹



Fig. 2: Viewgraph of the balanced photoreceiver OEIC, comprising two photodiodes with tapered input waveguides and a distributed amplifier

The design and the fabrication was entirely accomplished at FhG HHI, profiting from our complete InP processing line. Besides verifying a 3 dB bandwidth of about 36 GHz by an optical heterodyne measurement¹ a typical characterization of this type of balanced photoreceiver is done in the time domain to investigate the output pulse behaviour for identical optical input pulses at the two fibre ports. Fig. 3 shows the measurement results, which demonstrate the good bipolar symmetry of the balanced receiver and, moreover, the high power output capability of about 1.6 V differential amplitude.

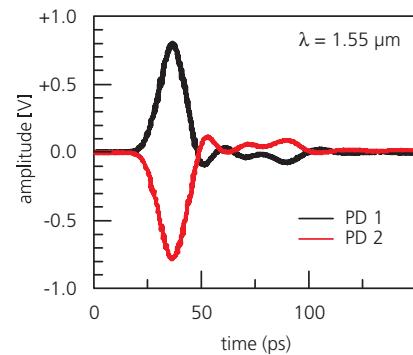


Fig. 3: Pulse response of the photoreceiver, measured with a 50 GHz sampling scope (FWHM of optical input pulses < 4 ps), illuminating PD1 and PD2 separately; measured FWHM is 14 ps

Due to increasing demands of our industry partners detectors and OEICs are packaged into conveniently small modules, completed with a fibre connector and V-type or 1mm connectors, see Fig. 4.

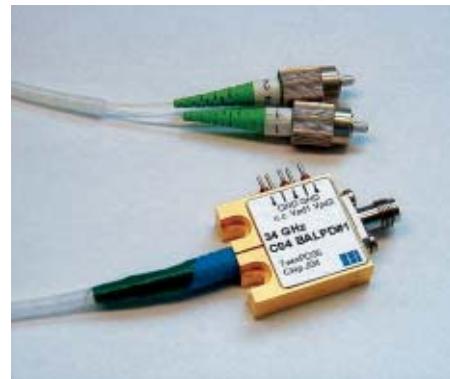


Fig. 4: Packaged balanced photodetector (50Ω -terminated) with two fibre inputs and a V-type electrical output; the biasing is accomplished via the pins at the side of the module

A crucial suitability test of the our photodetector was done within a DPSK system experiment. The balanced detector was used to convert the optically demultiplexed 40 Gbit/s data stream from a 160 Gbit/s OTDM signal to an electrical signal at 40 Gbit/s of RZ modulation format. The successful conversion is demonstrated by a widely opened eye diagram, as given in Fig. 5, which also shows quite low jitter.² The balanced detector fabrication scheme was licensed to our spin-off company u2t Photonics AG in Berlin.

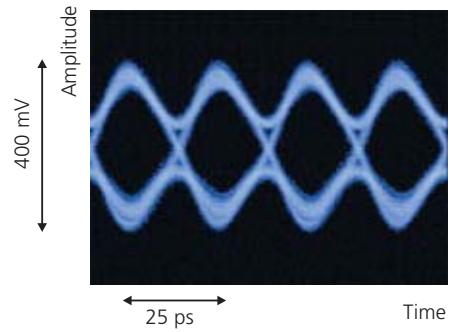
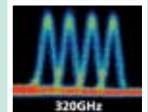


Fig. 5: 40 Gbit/s DPSK RZ signal detection using the 50Ω -terminated photodetector module

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1 A. Beling et al.: Monolithically Integrated Balanced Photoreceiver OEIC Comprising a Distributed Amplifier for 40 Gbit/s Applications, Proceedings of OFC 2004, Feb. 22-27, paper TuM5, LA, CA.

2 A. Beling et al.: Monolithically integrated balanced photodetector and its application in OTDM 160 Gbit/s DPSK transmission, Electron. Lett., 2003, 39 (16), pp. 1204-1205.



PHOTODETECTORS FOR FAST ETHERNET AND SENSOR APPLICATIONS

Telecommunication networks, Fast Ethernet, optical sensor systems – these are the fields of applications that top-illuminated photodiodes are developed for at FhI HHI. Our product spectrum includes single photodetectors as well as segmented devices and array arrangements, designed and manufactured according to the requirements of our customers.

Telekommunikationsnetzwerke, Fast Ethernet und optische Sensor-systeme – das sind die Einsatzgebiete der am FhI HHI entwickelten Top-beleuchteten Photodioden. Unser Produktspektrum umfasst Einzel-Photodetektoren, segmentierte Bauelemente und Array-Anordnungen, entworfen und hergestellt gemäß den Anforderungen unserer Kunden.

For both Fast Ethernet and sensor applications a high responsivity, a very low dark current and the suitability for straightforward, low-cost mounting techniques are of crucial importance. We established a fabrication technology for top-illuminated photodiodes based on InGaAs(P)/InP which fulfil these requirements. Mesa type devices with diameters of the active area between 16 µm and 2.5 mm have been realized. Their responsivity amounts to typically 0.9 A/W, for small area detectors dark currents as low as 0.1 nA are achieved. By varying the material composition a wavelength range of 1.0–1.65 µm is covered. If required the monolithic integration of a passive biasing network consisting of resistors and capacitors is feasible. The photodiodes are passivated by BCB layers to protect them against environmental influences and to minimize ageing effects. They are designed to be mounted by flip-chip techniques, alternatively conventional die and wire bonding can be used (Fig. 1).

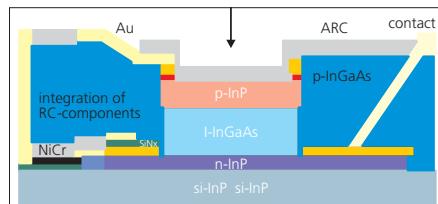


Fig. 1: Schematic drawing of a photodiode including a biasing network



Fig. 2: Microphotograph of a 15 GHz diode with integrated termination resistor for 50 Ohm matching

For Fast Ethernet applications, where also the high-frequency properties play a major role, a chip layout with coplanar interconnections was developed (Fig. 2). A careful optimization of the epitaxial layer stack and the device geometry led to an excellent RF performance of the photodiodes.

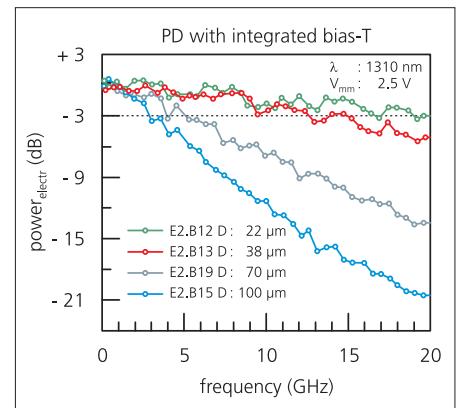


Fig. 3: High-frequency behaviour of photodiodes with different diameters of active area, determined by heterodyne measurements

For example 3dB bandwidths of up to 20 GHz are achieved (Fig. 3). Moreover the high uniformity of epitaxial material and processing makes it possible to fabricate arrays of photodetectors (Fig. 4).

At present a part of the photodetector types we have developed is being evaluated to obtain the qualification for outer space applications.

This work was partly funded by the State of Berlin, the European Community, and the DLR.

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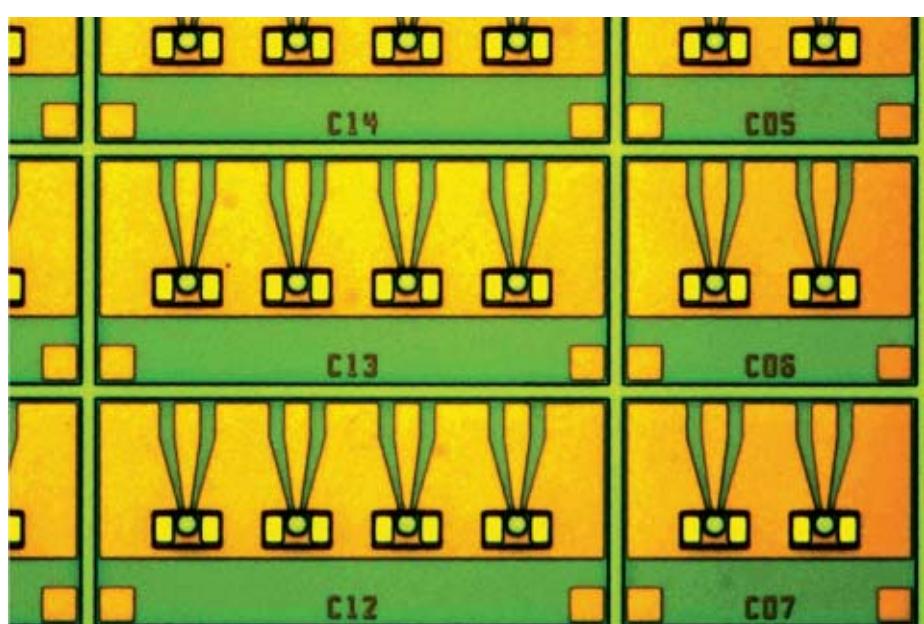
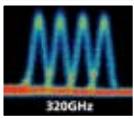


Fig. 4: Arrays of 10 GHz photodiodes



RECONFIGURABLE POLYMER-BASED OPTICAL ADD-DROP MULTIPLEXER

A polymer waveguide chip that integrates an array of digital thermo-optical switches (DOS) and two arrayed-waveguide gratings (AWG) has been developed to form a reconfigurable optical add-drop multiplexer (R-OADM).

In einem Polymer-Chip wurde ein rekonfigurierbarer optischer Add/Drop-Multiplexer monolithisch integriert. Der Multiplexer besteht aus zwei AWG-Elementen und einem Array von thermisch gesteuerten digital-optischen 2x2 Schaltern.

An optical add-drop multiplexer (OADM) represents a key component for all-optical WDM networks. It enables adding and dropping of any WDM channel, without impairing the other channels. Fig. 1 schematically illustrates the basic function of an OADM, handling three wavelength channels in this example. The input data signals in channels λ_1 and λ_3 are transmitted to the "OUT" port while channel λ_2 is dropped. Simultaneously, another signal also assigned to wavelength λ_2 is added.

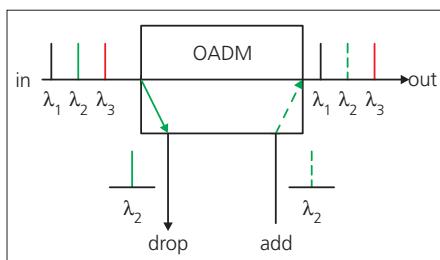


Fig. 1: Principle of an OADM

A reconfigurable 4-channel OADM can be composed of two different building blocks, an AWG for wavelength multiplexing and demultiplexing, and an optical switch for routing. Fig. 2 schematically depicts the 4-channel OADM architecture. The "input" AWG separates the incoming wavelengths of the IN and ADD

signals and directs them to the "output" AWG through a switch array. Depending on the switch state, the input signals will be routed to the "OUT" or "DROP" port. When the input signals are routed to the "DROP" port, the add signals will be routed to the "OUT" port. In the case shown in Fig. 2, the input signals $\lambda_{2\text{in}}$ and $\lambda_{4\text{in}}$ are dropped, while the "ADD" signals $\lambda_{2\text{ad}}$ and $\lambda_{4\text{ad}}$ are guided to the "OUT" port. Each of the four optical 2x2-switches is independently controlled to form a reconfigurable OADM.

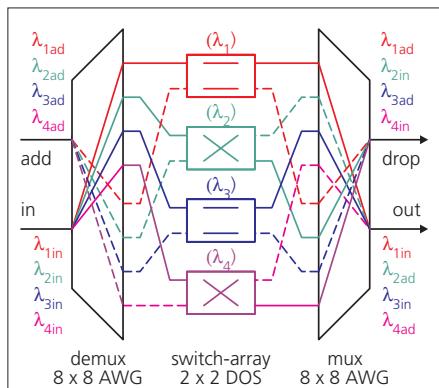


Fig. 2: 4-channel OADM architecture

Polymer based waveguide devices are attractive because of the large thermo-optic effect and their low-cost potential. Fig. 3 shows one of our polymer switch modules comprising a 4-channel 2x2 digital optical switch (DOS) array and an AWG module containing an 8x8 AWG chip with a spectral channel spacing of 200 GHz.



Fig. 3: Polymer-based DOS and AWG modules

For constructing a four channel OADM using these discrete components, 36 ports have to be connected with fibres (Fig. 4). Generally, for N

channels, the number of ports to be connected is $4*(N+1)$. For $N=40$, the port number to be connected will be 324. The fibre management in such assemblies will apparently be increasingly complicated.

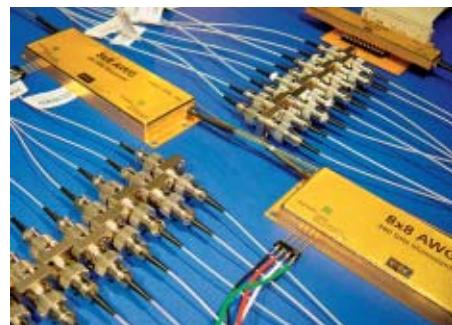


Fig. 4: OADM consisting of discrete components

These modules, developed in cooperation with OECA GmbH, Germany, and FhG-IZM are hermetically sealed thus guaranteeing excellent reliability.

By integrating the DOS array and the two AWGs onto a single chip, only four ports need to be connected with fibres for any channel number. Fig. 5 displays a fully monolithically integrated OADM chip featuring dimensions of 30 mm x 45 mm. Preliminary measurements showed very low crosstalk values in the range of -30 dB. The total optical path length of the OADM chip amounts to about 20 cm, leading to a high insertion loss in the present polymer device of 30 dB. If polymer materials with lower loss (0.1 dB/cm) are used, the total insertion loss may be reduced to well below 10 dB.

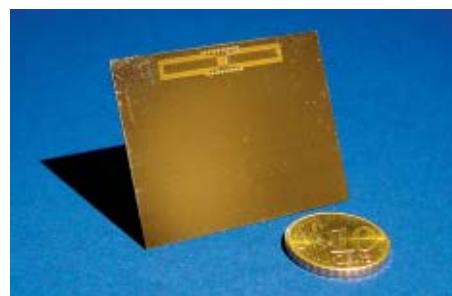
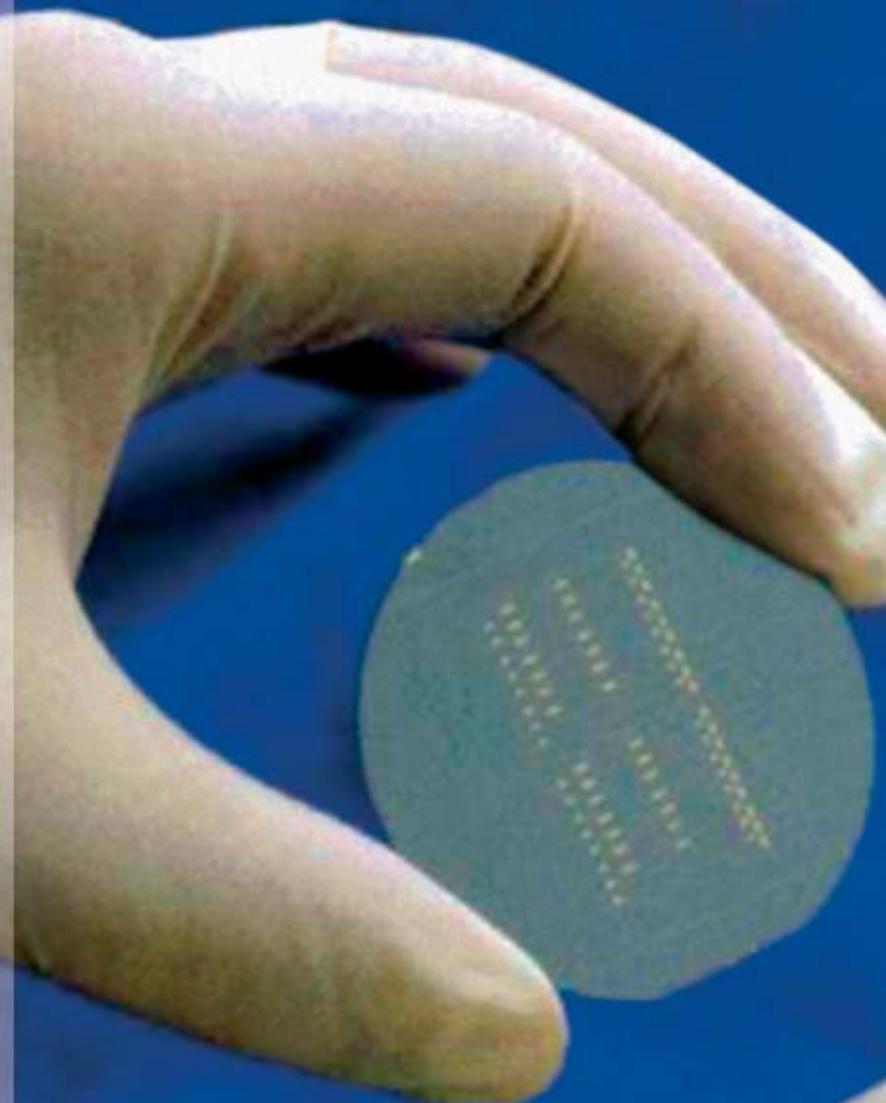
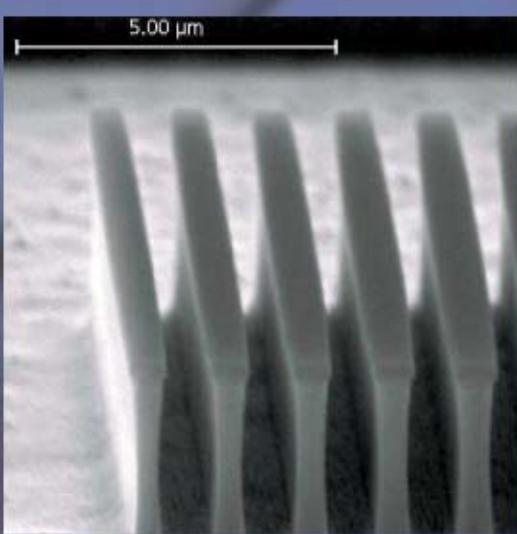
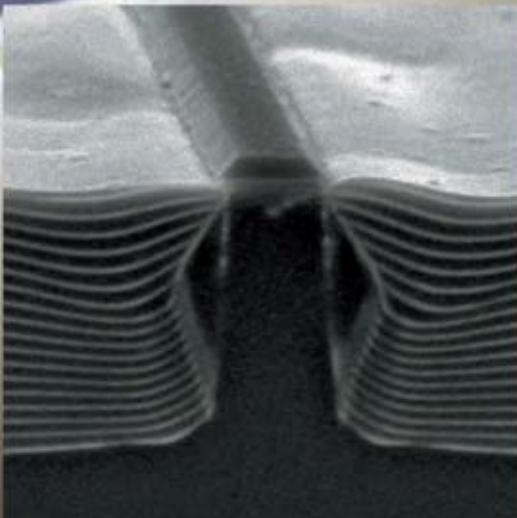
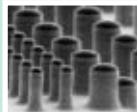


Fig. 5: Integrated polymer-based OADM chip

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Material and Processing Technologies for Photonic Components

Photonic components are key elements of optical communication systems; they comprise actively as well as passively operating devices. Their development and fabrication require the application of advanced technologies for material preparation and planar processing. Moreover, the chips have to be mounted in modules to make them ready for use in systems.

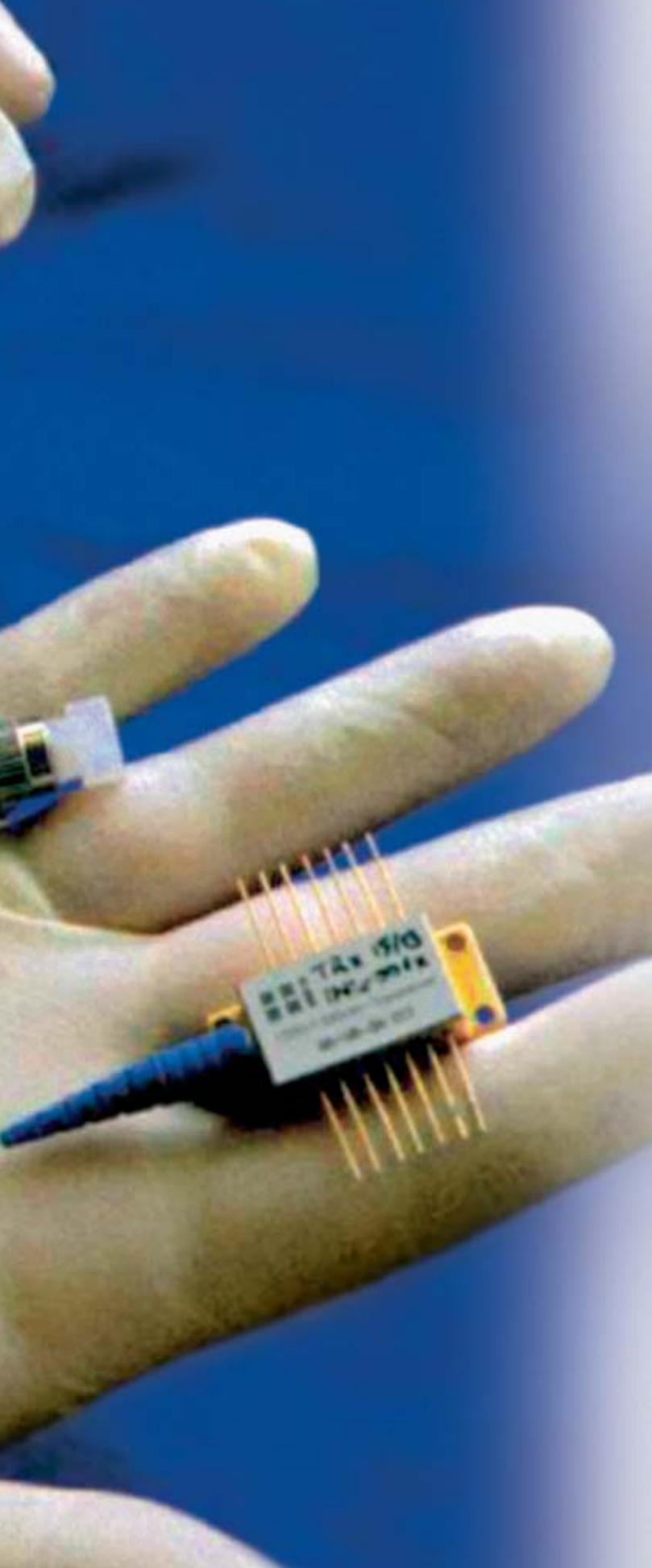
As the 'working horse' of the material technology the HHI runs a number of MOVPE machines enabling the growth of the whole spectrum of epitaxial III-V semiconductor layers based on indium phosphide. With this technique sophisticated, complex layer structures are formed as needed, for instance, for lasers, photodiodes, electro-optical modulators, and optical switches, as well as for high-speed transistors. In addition, MBE systems are available mainly for exploratory work such as the fabrication of new materials and structures specifically designed for ultra-fast optical switches.

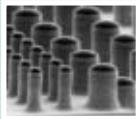
During the subsequent wafer processing steps electron beam lithography is employed to define structures on a nanometer scale, such as Bragg gratings and very short transistor gates. The e-beam system also serves for the fabrication of photomasks designed in particular for optoelectronic and photonic integrated circuits. The pattern transfer into the semiconductor surface is accomplished by means of ion beam and plasma processing, which are supported by in-situ monitoring in order to precisely adjust the etching depths. The planar wafer technology is rounded off by techniques for diffusion doping and for the deposition of dielectric and metal layers.

Besides the semiconductor technology, a laboratory is operated for polymer-based photonic devices.

In the field of chip mounting and assembly the activities are focused on the development and application of procedures for a low-loss, robust coupling of glass fibres to the input/output facets of devices, including anti-reflection coatings. Furthermore, electrical interconnections are designed and fabricated for the transmission of very high frequency signals (80 GHz and beyond).

The material, wafer and chip technologies are implemented in such a way that they form a complete processing line. At the same time a variety of alternative techniques and methods is available for R&D purposes. The entire component processing is subject to a quality management system. Most of the processes have been established to be compatible with industrial requirements, where special





emphasis is laid on achieving a high uniformity of the wafers and a good reproducibility from run to run. For partners from the industry, the chips are either fabricated in our own processing line as prototype series of small volume, or the component technology can be transferred to external production facilities. By playing this role HHI has already become an important partner for several SMEs, which supply the market with photonic components and modules. Moreover we offer individual services such as wafer epitaxy, photomask making, development and manufacturing of micro-optical devices, and module assembly according to customer specifications.

Material- und Prozesstechnologien für photonische Komponenten

Photonische Komponenten sind die Schlüsselbausteine optischer Kommunikationsnetze; sie umfassen aktive und passive Funktionselemente, deren Herstellung den Einsatz modernster Material- und Prozesstechnologien erforderlich macht. Schließlich müssen die optischen Chips zu Modulen aufgebaut werden, um sie in Systemen einzusetzen.

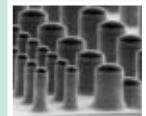
Als Basis für die Materialherstellung verfügt das HHI über mehrere MOVPE-Anlagen für die Epitaxie des gesamten Spektrums Indiumphosphid-basierter III-V-Halbleiterschichten. Dieses Verfahren ermöglicht die Erzeugung ausgeklügelter, komplexer Strukturen, wie sie für Laser, Photodioden, optische Modulatoren und Schalter sowie Hochfrequenz-Transistoren benötigt werden. Daneben stehen MBE-Anlagen vor allem für explorative Arbeiten zur Verfügung, wie z.B. die Herstellung neuer Materialien und Strukturen, die speziell für ultra-schnelle optische Schalter optimiert werden.

In der nachfolgenden Waferprozessierung wird zur Definition von Nanostrukturen, das sind z.B. Bragg-Gitter oder Transistor-Gates, eine Elektronenstrahl-Lithographieanlage neuesten Typs eingesetzt. Sie wird außerdem zur Herstellung von Photomasken insbesondere für optoelektronische und photonische integrierte Schaltungen benutzt. Die Strukturübertragung in die Halbleiteroberfläche erfolgt mittels Ionenstrahl- und Plasmaverfahren, die durch eine In-Situ-Kontrolle zur präzisen Einstellung von Ätztiefen unterstützt werden. Die Wafer-Technologie wird vervollständigt durch Verfahren zur Dotierungsdiffusion und zur Deposition metallischer und dielektrischer Funktionsschichten.

In Ergänzung zur Halbleitertechnologie betreiben wir ein Labor zur Herstellung optischer Polymer-Bauelemente wie Schaltmatrizen und Filter.

Die am Institut etablierte Aufbau- und Verbindungstechnik konzentriert sich zum einen auf die Herstellung verlustarmer, langzeitstabiler Ankopplungen von Glasfasern an die Eingangs/Ausgangs-Facetten der Bauelemente, die zuvor mit Entspiegelungsschichten versehen wurden; zum anderen werden elektrische Verbindungen für die Übertragung sehr hoher Signalfrequenzen (80 GHz und höher) entwickelt.

Die Material-, Wafer- und Chip-Technologien sind als vollständige Prozesslinie implementiert, die einem Qualitätsmanagementsystem unterliegt. Zugleich steht für F&E-Aktivitäten eine Vielfalt an alternativen Verfahren und Methoden zur Verfügung. Die Prozesse sind in der Mehrzahl industriekompatibel; besonderes Augenmerk wird auf die Erreichung einer hohen Uniformität auf dem Wafer und einer guten Reproduzierbarkeit von Durchlauf zu Durchlauf gelegt. Chips werden für Industriepartner entweder auf unserer eigenen Prozesslinie in Prototyp-Kleinserien hergestellt, oder die Komponententechnologie kann in externe Fertigungslien transferiert werden. Das HHI ist in dieser Rolle ein wichtiger Partner mehrerer KMU geworden, die photonische Komponenten und Module am Markt anbieten. Darüber hinaus erbringen wir einzelne Dienstleistungen wie Wafer-Epitaxie, Photomaskenherstellung, Entwicklung und Herstellung mikrooptischer Elemente und Modulaufbauten nach Kundenspezifikationen.



Photonic Technologies

Micro Fabrication Technology

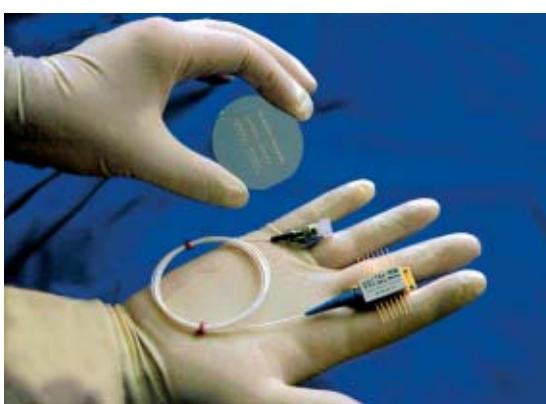
Head of Department	Udo Niggebrügge	Phone Fax e-mail	+49(0)30/310 02-550 -558 niggebruegge@hhi.fhg.de
Secretary	Iphigenia Janne	Phone e-mail	-557 janne@hhi.fhg.de
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Materials Technology

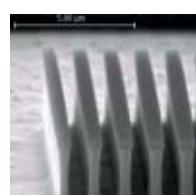
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Diffractive Optic, Micro- and Nanotechnology, Quartz-Glass, Silicon and Silica	Margit Ferstl	Phone e-mail	-430 ferstl@hhi.fhg.de

Integration Technology

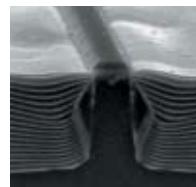
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InP-based OEICs	Helmut Heidrich	Phone e-mail	-538 heidrich@hhi.fhg.de



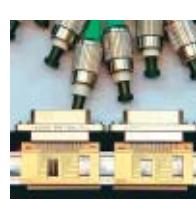
– From wafer to module –
In a complete line of material and processing technologies photonic components are realized, starting with epitaxy on semiconductor substrates and resulting in fully packaged devices.



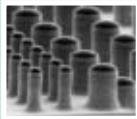
Cross-section view, taken by SEM, of a multi-layer structure grown by selective epitaxy on either side of a masked InP ridge. A high degree of flatness is achieved, which is a 'must' for the development of advanced laser devices.



SEM picture of a sub-micron, high aspect ratio structure formed in an InGaAsP/InP layer stack. Electron beam lithography and dry etching techniques were applied to fulfil the requirements for a precise device patterning even on a nanometer scale.



Photonic filter device with multiple optical input/output ports, mounted in a specially developed module and provided with fibre pigtails.



HIGH RESOLUTION ELECTRON BEAM LITHOGRAPHY – A TOOL FOR PHOTONIC NANOSTRUCTURES

Electron beam lithography is a key technology for microfabrication at the FHI HHI since more than 20 years. In the beginning of the year 2003 a new e-beam system was installed and successfully implemented. This system meets the demands for highly precise and flexible generation of structures down to the nanometer range and the requirements for fast and repetitive photomask and reticle production.

Seit über 20 Jahren ist die Elektronenstrahlolithographie eine Schlüsseltechnologie für die Mikrostrukturierung im FHI HHI. Anfang 2003 wurde eine neue Anlage installiert und erfolgreich implementiert. Dieses System ermöglicht es, sowohl die Anforderungen an hochpräziser und flexibler Strukturierung bis in den Nanometerbereich als auch hinsichtlich der schnellen und reproduzierbaren Herstellung von Photomasken und Reticles zu befriedigen.

Electron beam lithography (EBL) is one of the most used and proven technologies for the generation of micro- and nanostructures. Direct write EBL directly on the substrate combines the advantages of high resolution and maskless lithography. It is accepted as a potential candidate for the Next Generation Lithography tools by the Semiconductor Industry Association (SIA).

At FHI HHI the EBL is the technique of choice for the fabrication of photomasks and high resolution structures directly on substrates. Our new Leica EBPG5000plus system is a modern Gaussian beam vector scan system. Three different accelerating voltages (20 kV, 50 kV, and 100 kV) are provided. The system is equipped with a

thermal field emitter source that creates Gaussian beam profiles down to 10 nm in diameter which is necessary to fabricate Bragg gratings for semiconductor lasers (Fig. 1) or the novel photonic bandgap materials employed for ultra-compact optical devices (Fig. 2).

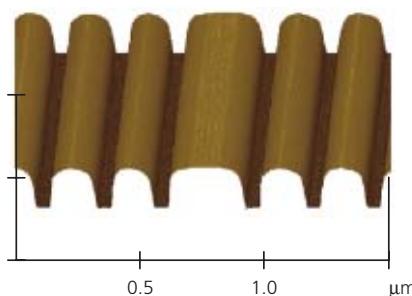


Fig. 1 AFM image of a Bragg grating with a $\lambda/4$ phase shift section in resist

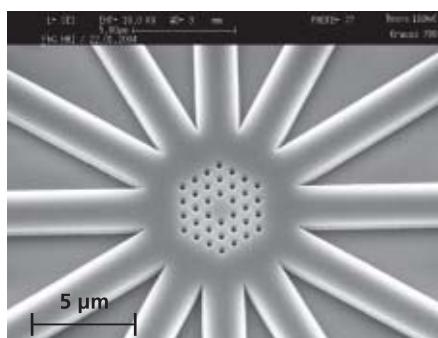


Fig. 2 SEM image of a photonic bandgap structure dry etched in SOI

The fabrication of circularly oriented micro optical elements like Fresnel Zone lenses (FZL) imposes very stringent demands on the precision of the electron beam processing.

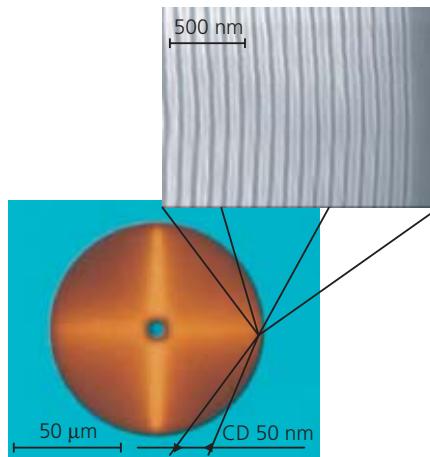


Fig. 3 Photograph of a FZL and SEM image of the critical lines dry etched in SiNx

We generate those patterns by use of the minimum address grid of 1.25 nm and the 16 bit decoder. Fig. 3 presents a FZL with a critical dimension (CD) of 50 nm at the outer pitch. By EBL also three-dimensional vertical profiles can be formed in resist layers. Applications for this are micro optical devices like Diffractive Optical Elements (Fig. 4) or multi-level FZLs.

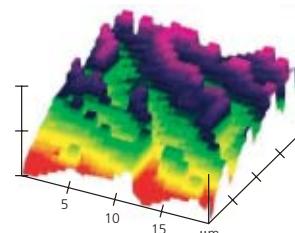


Fig. 4 AFM image of an 8-level Diffractive Optical Element in resist

For the generation of the layout a very flexible design tool in combination with a parameterised input desktop is available. Conversion of the layout data into exposure files is done by CATS (SYNOPSYS), Proxecco (PDF Solutions GmbH), and CAPROX (Sigma-C).

To meet the requirements of fast and cost-effective production the system is supplied with a 10 position airlock that makes it possible to automatically handle and expose substrates, also overnight and at weekends. Furthermore a high deflection frequency of up to 50 MHz contributes to a rapid exposure of the structures. For mask substrates all semi-standard mask sizes and thicknesses up to 6 inch, 250 mil and semi-standard wafers up to 6 inch are possible. Moreover we have gained a lot of experience in the application of special holders to expose on customer specific substrates.

The FHI HHI is recognised as a centre of excellence for the generation of micro- and nanostructures for research and development activities as well as for the fabrication of photomasks and reticles for industrial partners mainly from the optical industry.

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InGaAs/AlAsSb – A MATERIAL BASIS FOR ULTRA-FAST PHOTONICS

A promising basic concept for future ultrafast photonic devices is the use of intersubband transitions (ISBT) in multiple quantum well (MQW) semiconductor structures due to their inherent fast optical response.

Ein vielversprechendes Basiskonzept für zukünftige ultraschnelle photonische Elemente sind Intersubband-Übergänge (ISBT) in Halbleiter Multi-Quantentopfstrukturen (MQW) wegen der ihnen inhärenten schnellen optischen Antwort.

For ultrahigh speed optical signal processing which is expected to play a crucial role in future optical communication and possibly computing systems semiconductor elements, such as optical amplifier switches and saturable absorbers, with optical response times in the pico- to femtosecond range, will be required. In common optoelectronic devices the intrinsic speed is essentially governed by the characteristic time constants of carrier transitions between conduction and valence band (interband transition, IBT), ranging from pico- to nanoseconds. To reach the fs-range novel materials options are needed. Exploitation of intersubband transitions (ISBT) in compound semiconductor multiple quantum well (MQW) structures appears to be a viable approach due to the inherently ultra-short time constants associated with this type of carrier transition.

A schematic representation of ISBT in quantum wells (QW) is shown in Fig. 1. Our goal is to achieve ISBT in the 1.55 μm “telecommunications” wavelength window spacing, $E_1 - E_0$, in the QW of around 0.80 eV. This fundamental requirement restricts the choice of suitable ISBT materials since in most semiconductor heterostruc-

tures the conduction band discontinuity, ΔE_c , is considerably smaller than the fundamental band gap, allowing for ISBT wavelengths in the $> 3.5 \mu\text{m}$ region only. This is, however, not true for the material combination InGaAs/AlAsSb the conduction band discontinuity of which amounts to some 1.4 eV. This material system can be grown lattice-matched to InP.

Using molecular beam epitaxy (MBE) we have intensively investigated the growth of InGaAs/AlAsSb MQW structures and have characterized the relevant material properties by means of photoluminescence, IR absorption, and electrical measurements. MBE growth has been controlled by a home-made pyrometric set-up based on a commercial two-wavelength pyrometer. Operated on-line during deposition it provides direct quantitative information of growth temperature and growth rates and gives qualitative insight into the evolution of the surface quality.

Crystalline integrity and high optical quality have been achieved. The present work has mainly been directed towards reaching the 1.55 μm ISBT wavelength measured by IR absorption (collaboration with Forschungszentrum Rossendorf). As demonstrated in Fig. 2, until now a wavelength of as low as 1.9 μm has been achieved. To reach 1.55 μm further reduction of the QW thickness has proven necessary. 10 K photoluminescence (PL) and transport (collaboration with Paul-Drude-Institut and Humboldt Universität, Berlin) indicate a residual amount of interface roughness of the MQWs to be an issue. 10K PL results, shown in Fig. 3 in comparison to InGaAs/InAlAs, demonstrate good efficiency but broadening due to non-abrupt interfaces. Consistently, in-plane mobilities in the MQWs were found to decrease with decreasing layer thickness approaching zero at nominally 6 monolayers (ML). This finding suggests the inter-mixed

interface to be 3 MLs. Hence the key to reaching 1.55 μm ISBT is to further optimize the interface arrangement.

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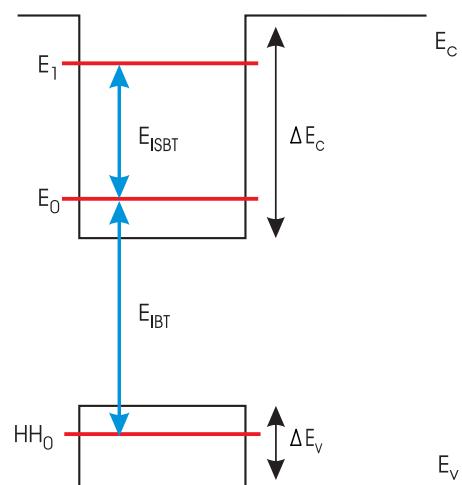


Fig. 1: Spatial band edge alignment in QW structure including IBT and ISBT

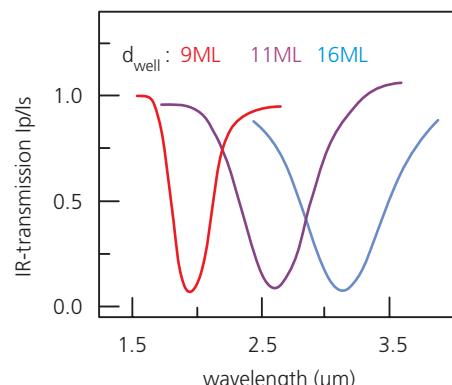


Fig. 2: ISBT related IR absorption spectra of InGaAs/AlAsSb MQW layers

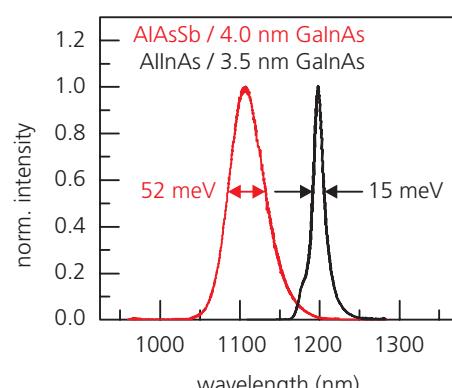


Fig. 3: Comparison of 10K IBT PL spectra of MQW layers



1.55 µm SIPBH FABRY-PEROT LASERS

1.55 µm Semi-Insulating Buried Hetero Structure (SIPBH) Fabry-Perot (FP) lasers have been developed and fabricated for applications in monolithically integrated mode-locked 40 GHz pulse lasers and commercial, 10 GHz external cavity pulse sources.

1,55 µm Fabry-Perot (FP) Laser mit semi-isolierenden Stromblockierungsschichten wurden entwickelt und hergestellt. Diese Laserstrukturen werden als aktive Elemente in monolithisch integrierten, moden gekoppelten 40 GHz Lasern und kommerziell erhältlichen, hybrid aufgebauten 10 GHz Pulslasern mit externem Resonator eingesetzt.

Buried heterostructure (BH) lasers integrating semi-insulating semiconductor material for current blocking (e.g. InP:Fe, Fig. 1) have the potential of better high frequency characteristics than those containing conventionally regrown pnp-InP layer sequences. Such BH laser structures are preferably chosen as basic building blocks in high speed optical semiconductor pulse laser components.

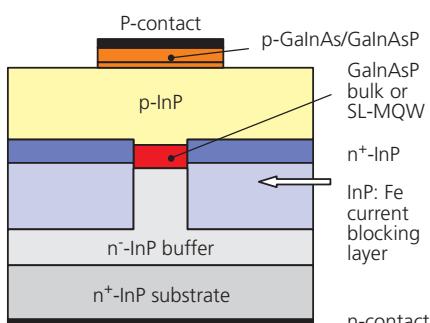


Fig. 1: Schematic cross-section of a SIPBH laser structure consisting of a semi-insulating InP:Fe current blocking layer

To this aim, 1.55 µm bulk and strained layer multi quantum well (SL-MQW) SIPBH FP lasers with semi-insulating InP:Fe current blocking layers have been developed and fabricated for

applications as active elements in monolithically integrated 40 GHz mode-locked lasers¹ and in commercially available 10 GHz external cavity pulse sources (cf. Fig. 2 and www.u2t.de). In case of the latter application, a saturable absorber is formed by ion implantation after FP laser chip processing and mounting.



Fig. 2: Commercially available 10 GHz external cavity pulse laser source consisting of FhG-HHI's implanted 1.55µm SIPBH FP bulk laser (u2t Photonics AG, Berlin)

The critical process steps within SIPBH laser fabrication are the preparation of the etched laser stripe prior to the selective area MOVPE regrowth of the InP:Fe layer and the MOVPE growth itself. A not optimized technology at this stage will cause unwanted leakage currents later at laser operation, which degenerate the device performance (e.g. increased laser threshold, strong decrease of laser efficiency with increasing injection current). Based on the preparation and regrowth procedure developed at FhG-HHI, a reproducible fabrication of 1.55 µm SIPBH FP bulk lasers, which show almost no leakage currents, was achieved. The typical threshold currents and optical output powers at the front facet of those lasers are 6.5 ± 1.5 mA and 23 ± 2 mW (at 200 mA), respectively (cf. Fig. 3).

Additionally, first SIPBH SL-MQW FP lasers have been fabricated, which integrate an active SL-MQW waveguide. Typical threshold currents are 3.5 ± 1 mA, and optical output powers of 27 ± 2 mW (at 200 mA current injection) were obtained at the cleaved laser output facets (cf. Fig. 4).

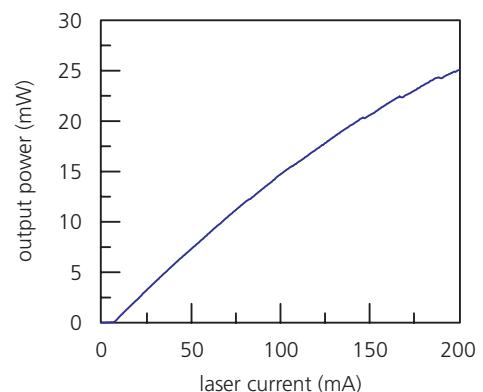


Fig. 3: Optical output power vs. injected laser current at the front facet of a typical SIPBH bulk Fabry Perot (FP) laser (device length: 300 µm, pulsed operation at room temperature)

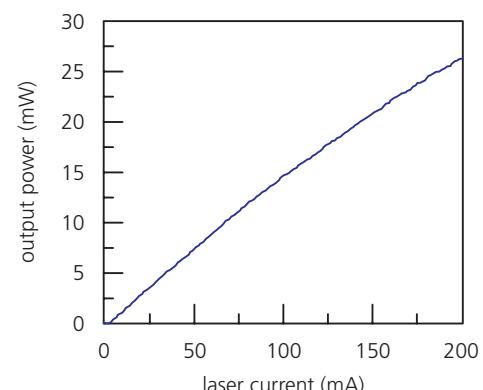
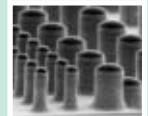


Fig. 4: Optical output power vs. laser current at the front facet of a SL-MQW SIPBH Fabry Perot (FP) laser (device length: 400 µm, pulsed operation at room temperature)

This work was supported by the Federal Ministry of Education & Research under grant 01 BP 070 and u2t Photonics AG Berlin.

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¹ cf. "Compact 40 GHz pulse laser modules with integrated monolithic mode-locked semiconductor laser" in this report.



PACKAGING OF HIGH-SPEED PHOTONIC DEVICES

In the Packaging Group of the FhI HHI we develop techniques for very high frequency electrical connections to opto-electronic devices and methods of fibre-chip coupling. They are applied to build complete photonic modules, as a service for R&D projects of our institute as well as for external customers.

In der Aufbau- und Verbindungsgruppe des FhI HHI entwickeln wir höchstfrequente elektrische Verbindungstechniken für opto-elektronische Bauelemente und Verfahren der Faser-Chip-Kopplung. Sie werden zur Realisierung kompletter photonischer Module eingesetzt, als Service sowohl für F&E-Projekte unseres Institutes als auch für externe Kunden.

The implementation of high-speed, high-capacity optical telecommunication networks requires the availability of adequately fast photonic components. The achievable bandwidth of such modules depends on the RF performance of the inserted devices itself, but also on the quality of the electrical interconnections to the environment. Several interconnection schemes are available for use in the high frequency region, i.e. coplanar waveguides (CPW), miniature coaxial cables, and microstrip lines.

As an example Fig. 1 shows a completed photodetector module which is suitable for receiving data rates up to 80 Gbit/s. It contains a waveguide-integrated InGaAs/InP photodiode with an optical spot size converter which makes it possible to attach a cleaved fibre directly to the input facet. The diode is wire bonded with only 160 µm bond length to a CPW on a quartz substrate, which leads to the 110 GHz output connector. The temperature cycling between 10 °C



Fig. 1: 80 Gbit/s photodetector module with fibre pigtail and 110 GHz RF connector



Fig. 2: 70 GHz interconnection with semi-rigid coaxial cable, CPW on alumina, and wire bonded photodiode

and 50 °C revealed a variation of the overall conversion efficiency of only 5%. Mechanical stress tests proved that the modules withstand accelerations of at least 40 g without any degradation.

A somewhat less expensive interconnection scheme for 70 GHz signals, in particular applied to lab-type modules, uses a semi-rigid coaxial cable with 0.9 mm outer diameter that fits to V connectors. It is glued to a short piece of a CPW on alumina, to which the active device is connected by wire bonds at the opposite end (see Fig. 2). The CPW metallisation and the alumina base are patterned by means of laser cutting.

For frequencies of 80 GHz and beyond microstrip lines will be used on which the devices can be mounted by flip-chip bonding. Therefore a technique for the fabrication of low-loss microstrip lines, composed of an Au metallisation, an insulating BCB layer, and a Cu-plated silicon substrate, has

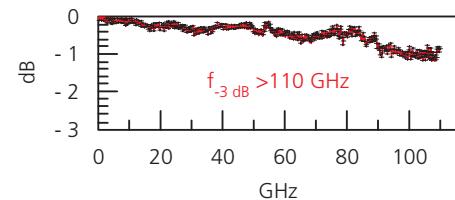


Fig. 3: Measured signal loss (S_{21}) of a high frequency microstrip line (Au on BCB, Si substrate with Cu layer, 2.9 mm length)

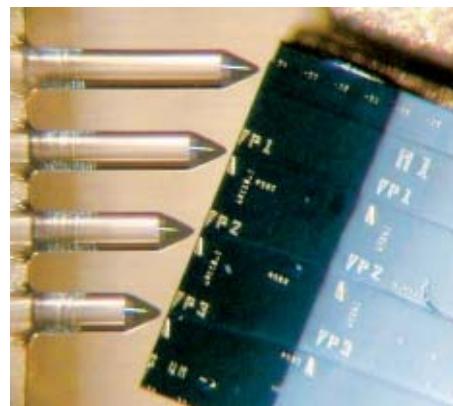
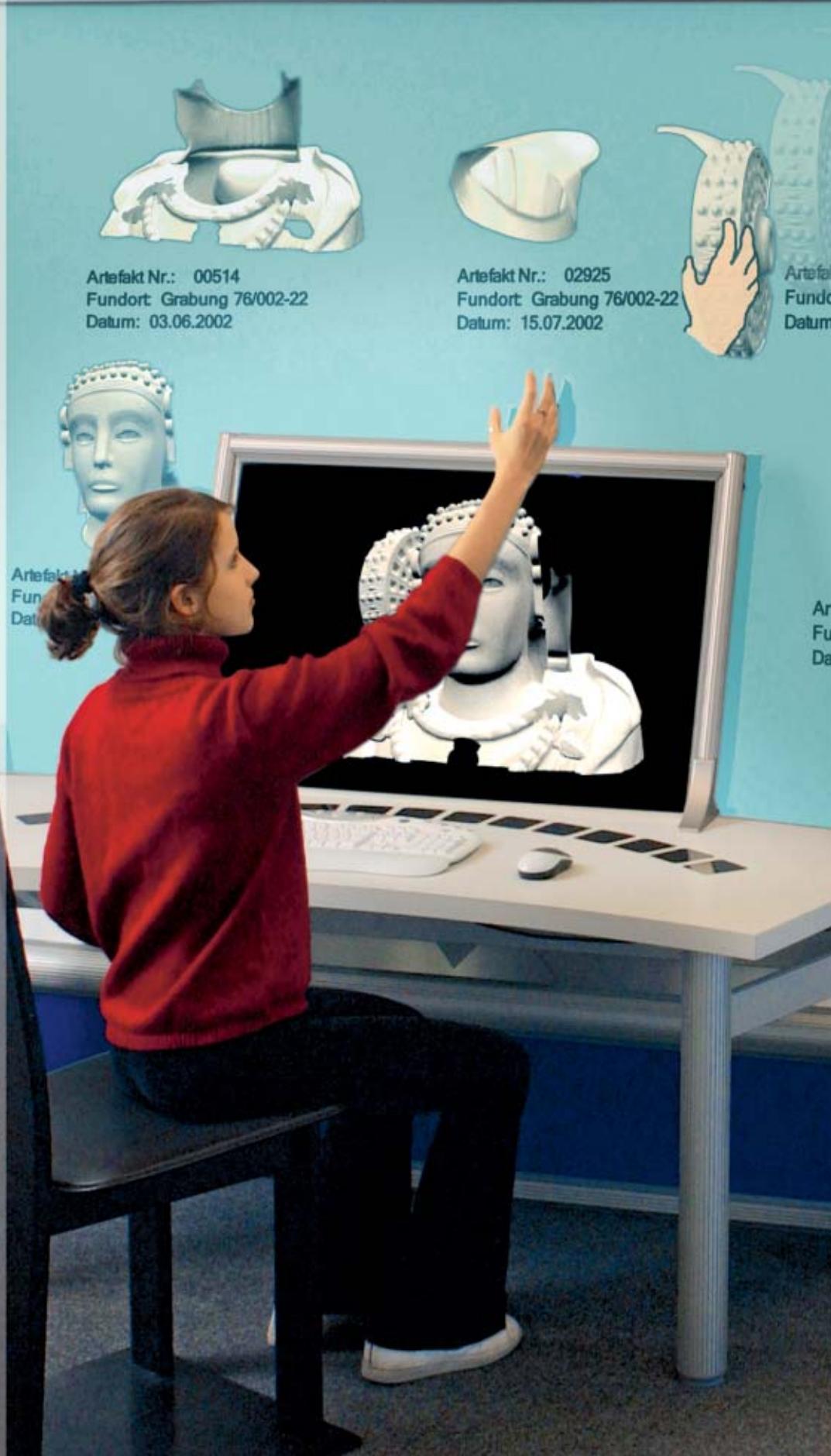
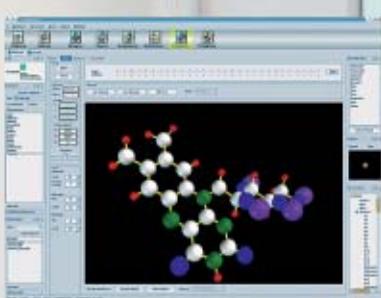


Fig. 4: Multi-fibre coupling of lensed fibres to an SOA chip with angled facets

been developed in a joint project with the FhI IZM. As deduced from S parameter measurements the specific loss amounts to less than 0.6 dB/mm, the 3 dB cut-off frequency exceeds 110 GHz (cf. Fig. 3).

In the field of fibre-chip interconnections in particular the assembly of all-optical signal processing devices containing semiconductor optical amplifiers is highly challenging. These devices include multiple input and output ports which, moreover, are of the angled facet type to minimize back reflections. As can be seen in Fig. 4 we accomplished the optical coupling by utilizing arrays of lensed fibres with steadily increasing protrusion length. This multi-fibre coupling technique is now applied to the packaging of monolithically integrated Mach-Zehnder interferometers for ultrafast all-optical signal processing applications such as demultiplexing of 160 GHz signals and 3R regeneration.

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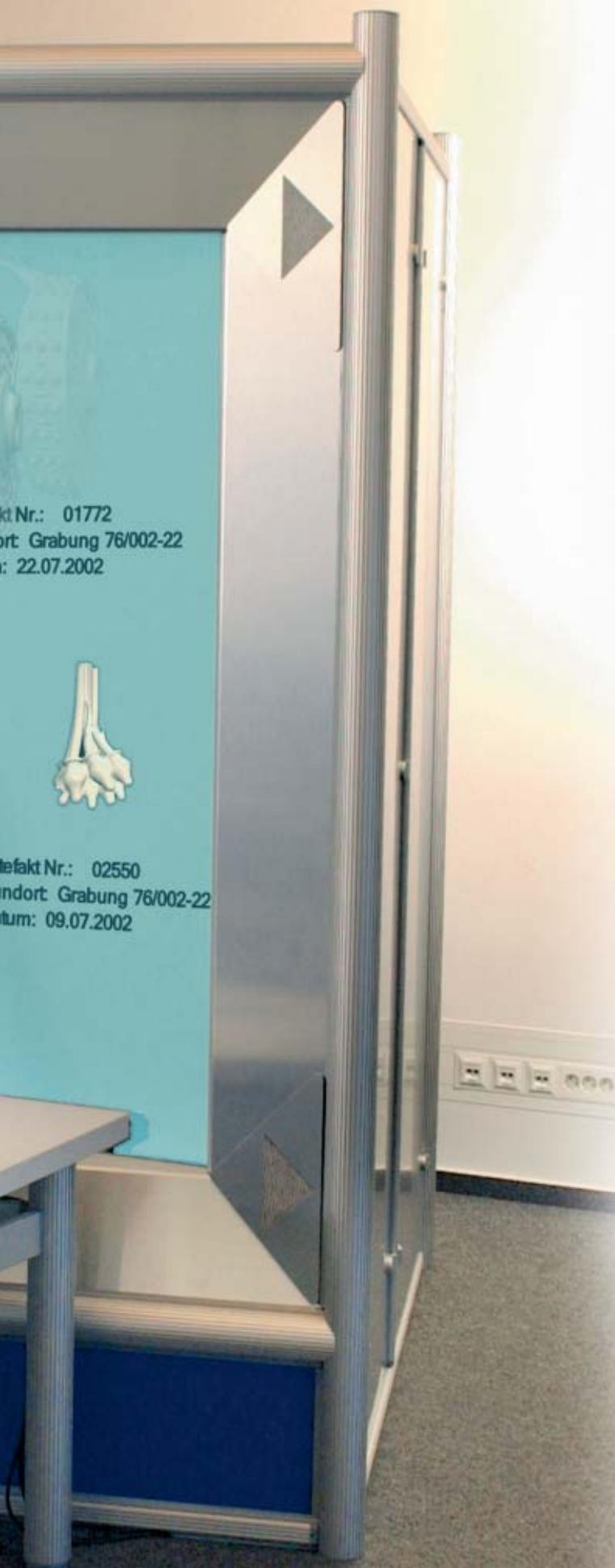




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Interactive Media - Human Factors

"Being digital" is significantly changing our role in the information age. We are rapidly moving from being 'classical' consumers of media content towards interacting users. **Interactivity** becomes the key concept of future media.

Broadband networks and novel devices for end users provide access to a sheer endless source of multimedia content – at work, at home and on the move. Formally placing the letter "e" in front of the old terms, traditional services are being transformed into eGovernment, eCommerce, and eLearning offering a complete new level of qualities and possibilities. In addition, the rapidly growing sector of interactive software delivers new solutions for the individual users. Software packages for creating and managing databases, containing text, digital music, photos and videos are now part of almost every new PC.

For the pacesetters of the digital future it is essential to recognise **new potentials** at an early stage and to utilise them in the best possible way. Providing tools and methods that empower users to smoothly interact with the emerging media technologies is a continuous challenge.

Compared with other innovations, interactive media take an exceptional position. We are confronted with extremely inhomogeneous groups of users – ranging from professional power users to novices; the devices and applications are extremely variable; the rate of innovation is high while standardisation is rather limited.

In close collaboration with partners from science and industry, we are creating solutions for interactive multi-media systems of the future. Our challenge is the design of next generation man-machine-interfaces, services and applications providing attractive and user-friendly access to multimedia information.

One of our core competences lies in the creation of novel **3D displays and multimodal sensing devices** allowing intuitive, smooth, and rich interaction between users and technology.

In this context we have implemented a set of at-a-distance, non-intrusive interfaces to sense people and to recognise non-verbal inputs through eye movements and hand gestures. Our remote stereo **Video Head Tracker** detects the 3D position of the eyes at a rate of 120 Hz. Interactive applications including 3D visualisations with motion parallax as well as optical systems can be adapted to the user's current vantage point without noticeable delay.



Our patented **Video Gaze Tracker** is particularly user friendly, since it works without individual calibration. Hence, in interactive applications it is possible to evaluate the user's current point of interest and to anticipate the user's wishes. Moreover, users may directly select interactive objects on the screen by simply looking at them.

With our multiple-baseline stereo **Hand Gesture Tracker** we achieve precise measurements in large interaction spaces by cascading sets of inexpensive chip cameras. In Mixed Reality applications users can touch and grab virtual objects floating in front of the 3D screen like they are used to do with real objects.

Our **sensing people interfaces** can be tailored according to all relevant parameters including range, precision, speed, operating conditions and costs. Beyond that, special procedures extract and describe personal features and data in digital video. Such sensing people functionalities are fundamental to a range of intelligent-camera applications used in surveillance, biometric-based personal identification and verification, as well as off-line description of video contents.

We develop **3D technologies** allowing users to watch stereoscopic video and 3D computer graphics without special stereo glasses. Our displays outperform competing technologies since they perfectly separate the stereo channels and provide extremely clear, high-resolution pictures (2 x 1600 x 1200 RGB pixels on 30 inch screen).

At the same time the patented optical system solves the accommodation conflict when users interact with virtual objects. This system enables perfect seamless mixture of virtuality and reality in **Mixed Reality** applications. Our special 3D flat-screen displays show interactive content in photo-realistic quality for desktop and kiosk applications (1600 x 1200 RGB pixels on 21.3 inch LCD screen).

In combination with the Video Hand Tracker, users can press virtual keys floating in front of the display ("touchless touch screen"). Portable Mixed Reality displays with integrated video based tracking are under development.

eGovernment services are currently being developed in cooperation with the Senate of Berlin. Our mobile terminal takes government service to the citizens – when and where they are needed – in shopping centres, in hospitals, and in homes for the elderly. Sensitive personal data are transferred via secured wireless interfaces.

In order to handle the increasing amount of multimedia data we develop automatic tools for **video analysis and annotation**. Novel search, filter and visualization methods

for multimedia data allow users to intuitively browse and search in large video archives. The multimedia descriptors used are conformable with the MPEG-7 standard.

Products in information technology should be adapted to the needs and abilities of their future users. Because successful marketing depends on user-friendly products, it is important to consider human factors in developing new products. Even at the earliest stages of conception and design, user-centred design helps create products that are user-friendly and marketable. Our **Human Factors Test Center** (HFTC) offers tests and consultation for all phases of the development of information technology services, systems, and devices. Our main goal is the fine-tuning of technology to the needs of the user in order to provide easy to use and satisfactory products.

Our services include the analysis of user requirements, experts' assessment for the usability of products and prototypes, usability tests, design studies, accessibility of web content for people with disabilities, and consultation in strategic decisions concerning future product lines.

In addition, the HFTC supports developers in designing websites, which meet with the special requirements of handicapped users (Web Accessibility).



Interaktive Medien – Human Factors

Die Digitalisierung der Medien verändert mit Macht unsere Rolle als Nutzer: Wir werden von schlichten Konsumenten eines weitgehend vorgefertigten Medienangebots mehr und mehr zu aktiven Anwendern. Die **Interaktivität** entwickelt sich zum alles bestimmenden Merkmal künftiger Medien.

Breitbandige Netze und neuartige Endgeräte verschaffen uns Zugang zu den schier unerschöpflich sprudelnden multimedialen Informationsquellen des Internet – am Arbeitsplatz, am heimischen PC und unterwegs. Traditionelle Dienste bekommen durch das vorangestellte kleine „e“ (wie in eCommerce, eLearning, eGovernment) völlig neue Qualitäten und Möglichkeiten. Hinzu kommt die nicht minder rasant wachsende Vielfalt interaktiver Softwareanwendungen. Programme zur Erstellung eigener Datenbanken mit selbst gestalteten Texten, digitaler Musik, Urlaubsbildern und Videos gehören inzwischen zur Bonussoftware bei jedem PC-Kauf.

Für die Schrittmacher der digitalen Zukunft gilt es, **Potentiale** frühzeitig zu erkennen und in der bestmöglichen Weise nutzbar zu machen. Als besondere Herausforderung stellen sich dabei die Bereiche heraus, die das reibungslose Zusammenspiel von Mensch und Technik unmittelbar betreffen.

Im Vergleich zu allen anderen technischen Neuerungen nehmen die interaktiven Medien eine Sonderstellung ein, hat man es doch hier mit einer ausgesprochen inhomogenen Nutzergruppe zu tun, die sowohl professionelle Poweruser als auch absolute Laien umfasst; die Geräte und Anwendungen sind äußerst vielfältig; die Innovationsrate ist sehr hoch – gleichzeitig gibt es noch recht wenige Standards, auf die man aufbauen kann.

In enger Zusammenarbeit mit Partnern aus der Industrie und Wissenschaft entwickeln wir Lösungen für die multimediale Interaktion und Kommunikation der Zukunft. Unser Ziel ist die Schaffung von Endgeräten, Systemen und Anwendungen, die einen attraktiven und nutzerfreundlichen Zugriff auf multimediale Daten und interaktive Dienste ermöglichen.

Eine unserer Kernkompetenzen liegt auf dem Gebiet neuartiger **3D-Displays und multimodaler Interaktionssysteme**, die ein intuitives, reibungsloses Zusammenspiel von Mensch und Technik ermöglichen.

In diesem Zusammenhang entwickeln wir eine umfassende Palette von Technologien zur berührungslosen Erfassung von nicht-verbalen Eingaben des Anwenders, z.B. durch

Blickbewegungen und Handgesten. Unser **Video Head Tracker** ortet die Augen des Menschen (3D-Koordinaten) mit einer Messrate von 120 Hz. Damit lassen sich sowohl interaktive Anwendungen als auch optische Systeme verzögerungsfrei an den aktuellen Blickwinkel des Betrachters anpassen.

Unser patentiertes Verfahren zur **Messung der Blickrichtung** erfordert keine individuelle Kalibrierung und ist daher besonders nutzerfreundlich. In interaktiven Anwendungen kann damit auf den aktuellen Interessenschwerpunkt des Betrachters geschlossen werden. Interaktive Objekte können durch einfaches Anblicken ausgewählt werden.

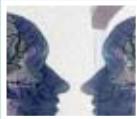
Mit unserem **Stereo Hand Tracker** erreichen wir durch Kaskadierung einfacher Chipkameras eine hohe Messgenauigkeit in einem großen Erfassungsbereich. In Mixed-Reality-Anwendungen können damit virtuelle Objekte, die dank stereoskopischer Verfahren scheinbar vor dem Display schweben, wie Realobjekte mit der bloßen Hand „berührt“ werden.

Unsere Tracking-Technologien können hinsichtlich aller relevanten Parameter wie Erfassungsbereich, Präzision, Geschwindigkeit, Einsatzbedingungen und Kosten maßgeschneidert werden. Darüber hinaus ermöglichen spezielle Verfahren eine automatisierte Beschreibung von Personen-daten in digitalen Bild- und Audioquellen hinsichtlich des Aufenthaltsorts, der Aktivität und Identität und sonstiger personenbezogener Informationen. **Sensing-People-Funktionalitäten** mit intelligenten Kameras bilden so unter anderem die Grundlage künftiger sicherheitstechnischer Systeme.

Wir entwickeln **3D-Technologien**, die das Betrachten von stereoskopischen Videobildern und 3D-Computergrafiken ohne eine spezielle Stereobrille ermöglichen. Unsere Displays zeichnen sich durch eine brillante und besonders augenverträgliche Stereowiedergabe aus. Beispielsweise ermöglicht unser Verfahren eine perfekte Trennung der Stereokanäle bei extrem hoher Bildauflösung (2x1600 x 1200 RGB-Bildpunkte auf einem 30 Zoll Bildschirm).

Das patentierte optische System löst zugleich den Akkommodationskonflikt bei der Interaktion mit virtuellen Objekten und bietet so eine perfekte, nahtlose Mischung von Virtualität und Realität in **Mixed-Reality-Anwendungen**. Spezielle 3D-Flachbildschirme können als Arbeitsplatzdisplay oder 3D-Kiosk gestaltet und interaktive Inhalte in fotografischer 3D-Qualität dargestellt werden (1600x1200 RGB-Bildpunkte auf einem 21,3 Zoll Bildschirm).

In Verbindung mit unserem Hand Tracker kann der Anwender virtuelle Auswahltasten betätigen, die vor dem Display



schweben („touch-less touch screen“). Portable Mixed-Reality-Displays mit integriertem videobasierten Tracking sind in der Entwicklung.

Unter Beteiligung der Berliner Senatsverwaltung für Inneres entwickeln wir ein Endgerät, mit dem mobile Bürgerberater **eGovernment-Dienstleistungen** in Einkaufszentren, in Krankenhäusern und Altenheimen erbringen können. Dabei werden auch sensible personenbezogene Daten über entsprechend gesicherte Luftschnittstellen transportiert.

Um die zunehmende mediale Datenflut zu bewältigen, entwickeln wir ein **Video-Retrieval-System** der nächsten Generation. Neuartige Such-, Filter- und Visualisierungsverfahren ermöglichen eine wesentlich einfachere Sichtung und Nutzung von großen Video-Datenbanken, ohne dass dabei auf manuell erstellte Annotationen zurückgegriffen werden muss. Die Beschreibungen der Bild- und Tondaten sind konform zum MPEG-7 Standard.

Produkte der Informationstechnik lassen sich umso besser vermarkten, je mehr sie auf die Bedürfnisse und Fähigkeiten ihrer zukünftigen Nutzer zugeschnitten sind und je mehr die menschlichen Aspekte (human factors) berücksichtigt werden. Bereits bei der Konzipierung neuer Produkte erhöht ein nutzerzentriertes Vorgehen die Chance der späteren erfolgreichen Vermarktung. Unser **Human Factors Test Center** (HFTC) bietet als einen besonderen Service Tests und Beratung in allen Phasen der Entwicklung von Diensten, Systemen und Endgeräten der Informationstechnik.

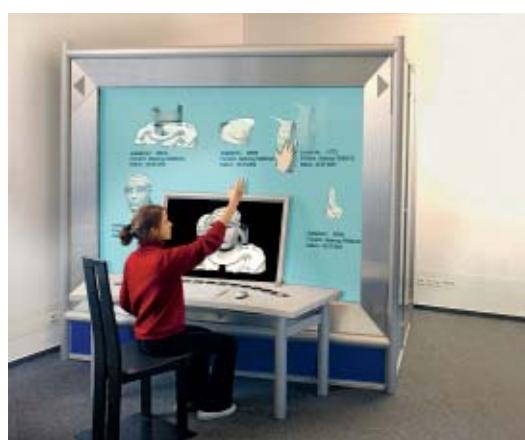
Unser Leistungsangebot umfasst die Analyse von Nutzeranforderungen, die Evaluierung von Produkten und Prototypen durch Human Factors Experten, sowie Usability Tests mit Versuchspersonen, Designstudien und die Beratung bei strategischen Entscheidungen über Produktlinien.

Darüber hinaus unterstützt das HFTC Anbieter von Webangeboten in der Erstellung barrierefreier Websites, die auch den erhöhten Anforderungen von Behinderten gerecht werden.



Interactive Media – Human Factors

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Novel interactive workplace allowing users to "drag" computer-generated or scanned 3D objects from a big rear-projection screen and "drop" them into a 3D display for direct manipulation. The video-based device for hand-gesture recognition is embedded in the desktop. The special 3D display creates a floating 3D image hovering over the desk



Mobile office for citizen services.
All devices needed for wireless services are integrated in a box



The Free2C Kiosk combines a high-resolution autostereoscopic 3D display with a gesture recognition device integrated into the panel. This novel information terminal is perfectly suited for applications in high-tech showrooms, convention halls, airports, and shopping malls



The Workbench^{3D} is a development tool helping software designers create multimedia and multi-modal applications with the Microsoft Visual Studio®.NET environment



FREE2C – HIGH-RESOLUTION AUTOSTEREOGRAPHIC DISPLAYS WITH USER TRACKING FOR DESK- TOP AND KIOSK APPLICATIONS

The availability of 3D displays is essential for the reproduction of stereoscopic content in desktop and kiosk applications. The new *Free2C* 3D display overcomes most deficiencies of common 3D displays available on the market.

Die Verfügbarkeit von 3D-Displays ist essentiell für die Wiedergabe hochwertiger stereoskopischer Inhalte in Büro- und Kioskanwendungen. Das neue Free2C 3D-Display überwindet viele Unzulänglichkeiten bereits erhältlicher 3D-Displays.

The *Free2C* 3D display is currently the most advanced development in autostereoscopic (no viewing glasses necessary) display technology. This display serves as the end-user terminal in 3D-TV, internet browsing and kiosk applications. *Free2C* is based on a special head-tracking lenticular-screen 3D display principle, allowing free head movements in three dimensions at unprecedented image quality. The particular design of the lens plate ensures that the stereoscopic images are almost perfectly separated (no ghosting). Hence, the *Free2C* display meets the essential requirements for comfortable viewing of extended stereoscopic depth volumes.

A novel dual-axes kinematic device adjusts the lens plate in real-time without any noticeable delay when the observer changes his/her viewing position. According to viewers' displacements a lens plate is tracked in dual axes at a precision of about 10 µm which enables the viewer to perform lateral and frontal movements while watching excellent stereoscopic video images (see Figure 1a/b). The implemented high-speed video head tracker operates at 120 Hz measurement rate.

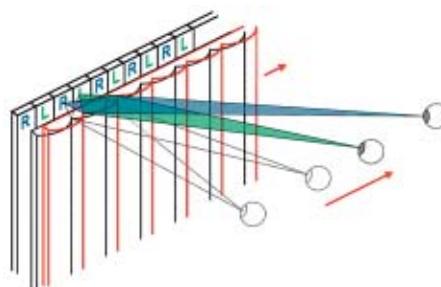


Fig. 1a: Lateral user movement

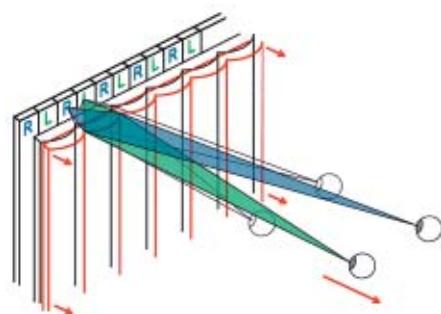


Fig. 1b: Frontal user movement

Display Characteristics

- No special aids like viewing glasses
- Free positioning of a single viewer within an opening angle of about 60 degrees
- Extremely low crosstalk
- High spatial resolution (1200x1600 RGB)
- Excellent brightness and color reproduction



Fig. 2: The Free2C 3D display

Typical 3D Applications

- Appealing presentations in kiosk environment (trade shows, museums, etc.)
- Medical science (endoscopy and minimal invasive surgery)
- Design and engineering (CAD, virtual prototyping)
- Architecture (simulation und visualization of planned projects)
- Education and simulations (driving/flight simulator, training of complex operations)
- Exploration in dangerous or inaccessible environments (archeology, oceanography, contaminated environments)
- Entertainment (3DTV, PC gaming)



Fig. 3: The Free2C 3D kiosk

One promising application for stereoscopic representations are immersive kiosk presentations. An integration of our *Free2C* technology in a kiosk system give birth to our newest development. The *Free2C* Kiosk is ideally suited for museums, conventions, airports, trade shows, malls, and stores. It can offer fast and effective access to products or services. Furthermore, the *Free2C* Kiosk facilitates elegant interaction between customers and presented content. The integration of a video based hand tracker supports easy interaction by means of analysing hand gestures.

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A FAMILY OF VIDEO-BASED TRACKING MODULES FOR INTERACTIVE MEDIA

We introduce various vision based head, hand, gaze and object tracking devices that can be used in human-computer-interaction.

Wir beschreiben verschiedene Computer-Vision basierte Kopf-, Hand-, Blick- und Objekt-Tracking Module für die Interaktion mit einem PC.

We believe that in the near future traditional computer input devices like the keyboard and the mouse are going to be supplemented or replaced by more natural interfaces. For many applications, vision-based trackers are suited as interaction devices.

We have developed a family of non-intrusive, markerless computer vision based modules for human-computer-interaction in indoor environments. The modules are designed to work with a variety of cameras ranging from low cost to high end devices allowing to find a best compromise between performance and price. All trackers may communicate via established protocols (e.g. Polhemus protocol on serial line) as well as via specially designed DCOM interfaces.



Fig. 1: The Free2C 3D display uses the head tracker to optically address the user's left and right eye. The hand tracker allows natural interaction with virtual objects floating in front of the screen.

Head tracking is essential for showing 3D content with autostereoscopic

displays. Our head tracking module tracks the user's eye position with a common webcam as well as with a 120Hz high speed camera. A special stereo version provides improved accuracy and/or an extended tracking range.

Our **gaze tracking** module applies a special cornea reflex method. It senses the user's current point of fixation (lines-of-sight of both eyes) at a rate of 50Hz with a single stationary camera (Fig. 2). Due to the wide-angle optics, the user may move in a range of 30x30x30cm.

Gaze tracking can be used to trigger context sensitive applications (e.g. when looking repeatedly at certain screen elements) as well as in usability research, in order to study the visual



Fig. 2: Four switchable infrared spot-lights and a stationary high-resolution camera are used to measure the user's current point of fixation.

reaction of test subjects.

Pointing with the fingertip is an easy and natural way to interact with objects shown on a display. Our **hand tracker** measures the 3D position of the user's fingertip at a rate of 50Hz. Besides the pointing actions, some simple gestures signalling stop, start, left and right are recognized. In order to increase the tracking range, the basic pair of stereo cameras can be extended by additional cameras.

Without using any markers, the video-based **object tracker** computes the position and orientation of known, geometrically defined objects. These data are used to overlay 3D graphical

objects and to annotate information about the scene on live video. The object tracker can also be used as a



Fig. 3: The object tracker camera on top of the tablet PC captures the real scene. The software is recognizing the position and orientation of a known object (in this example an LCD monitor) and correctly matching a virtual texture. All processing is done with a simple webcam in realtime. The user can freely move the tablet PC.

flexible interacting device to manipulate virtual objects with real tools. Using sensor fusion techniques, the various tracking modules may be combined to set-up novel interaction tools allowing **smart applications**.

For example, a new and very natural pointing tool is created by combining the head (pupil) tracker with the hand (finger tip) tracker; with such a tool the user can easily control the position of a marker on the screen by pointing in the desired direction (see Fig. 1).

Tracking the users gaze vector allows a speech recognition engines to react more reliable and context sensitive.

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WORKBENCH^{3D} – A DEVELOPMENT ENVIRONMENT FOR MODELLING AND VISUALIZATION OF INTERACTIVE MULTIMEDIA APPLICATIONS

The Workbench^{3D} is a development tool which helps software designers create multimedia and multi-modal applications with the Microsoft Visual Studio® .NET environment. It supports the latest DirectX® technologies, multiview systems, HHI video trackers and 3D display devices.

Die Workbench^{3D} ist eine Entwicklungshilfe für Softwaredesigner für das Erstellen von multimedialen und multimodalen Anwendungen unter der Microsoft Visual Studio® .NET Umgebung. Es unterstützt DirectX®-Technologien, Multiviewsysteme, HHI-Videotracker und 3D-Displays.

Regarding the enormous potential of virtual worlds, appropriate technical systems are being developed in the Mixed3D project to enable work in virtual environments. Among these systems are autostereoscopic displays and video based input devices which evaluate head, gaze and hand movement of the user and convert these into input data for the VR environment. In this way users may use various modalities for intuitive interactions.

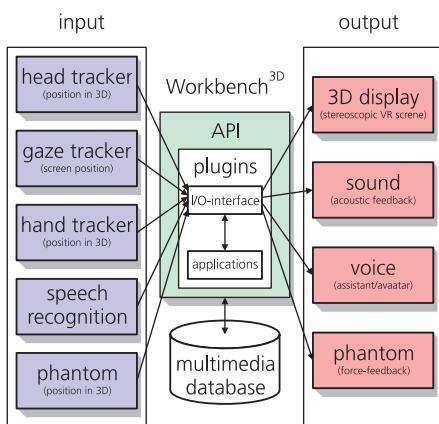


Fig. 1: Central management of the VR-System using Workbench^{3D}

The Workbench^{3D} consists of a .NET library (API, Figure 1) written in C# and a corresponding core application which manages plugins and drivers written with this API. In this way interactive systems can be created for a variety of fields in science, industry, culture and entertainment (Figures 2 and 3). It is especially easy to develop experimental systems (for example in usability research) and demonstrators which can be used on trade fairs.

In order to guarantee flexible adjustment to different hardware configurations, the Workbench^{3D} supports visualization on multiple monitors (combined 2D/3D displays), communication between computers via .NET, environmental sound as well as voice input and output using an avatar and the force feedback device PHANTOM™ from SensAble Inc. The inheritance methods of the .NET Framework make it possible to enhance the API with other technologies.

In the 2D area, the graphical interface design is realized with Visual Studio tools (Designer). The Workbench^{3D} scene graphs describe the VR environments (3D GUI) which are then rendered in arbitrary windows in real-time. Elements such as cameras, lights, geometric primitives, enhanced interactive objects and external model files can then be dynamically managed including all appending attributes like transformations, colors and textures. An event and animation system helps the programmer to define new interactions. The 3D GUI can likewise appear playful or functional.

Another powerful feature of the Workbench^{3D}, granted by the special traits of the Fraunhofer HHI 3D devices (autostereoscopic displays and 3D trackers), are applications in the field of Mixed Reality combined with natural interactions. In this way users may interact with virtual objects in a new dimension or navigate in complex database contents.

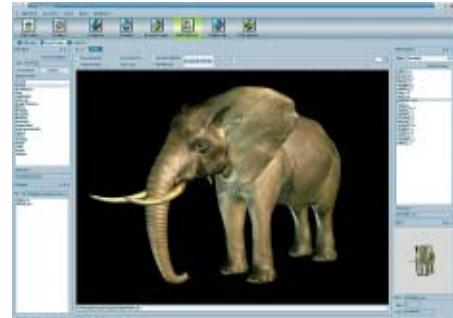


Fig. 2: Plugin for managing, viewing and rotating 3D models

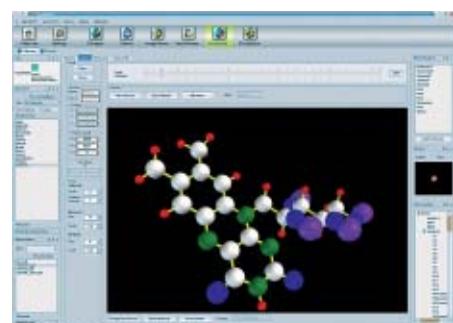


Fig. 3: Plugin for a molecular designer which is capable of loading any PDB file, modifying it and then saving it.

The simple manner to write new applications for the Workbench^{3D} with integrated 3D technologies provides the designer and ergonomist with more room for creating user-friendly, experience orientated and forward-looking computer systems.

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

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THE OFFICE IN A BOX – MOBILE SERVICES FOR CITIZENS

In the future, it will be possible to meet mobile citizen consultants in shopping malls, on weekly markets, in hospitals or in residential homes for the elderly. One will be able to let there renew one's passport, to declare a new domicile, or to let modify one's wage tax card. For such kind of services HHI developed, among other things, an "office of citizen services case". This case contains all terminal components required for mobile citizen services.

In Zukunft wird es möglich sein, in Einkaufszentren, auf Wochenmärkten, in Krankenhäusern oder Seniorenhäusern mobile Bürgerberater zu treffen, bei denen man seinen Personalausweis verlängern, seinen Wohnsitz ummelden oder Lohnsteuerkarten ändern lässt. Für solche Dienstleistungen wurde vom HHI ein „Bürgeramts-Koffer“ entwickelt. Dieser Koffer enthält alle für mobile Bürgeramts-Dienstleistungen wichtigen Komponenten.



Fig. 1: A mobile office of citizen services

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

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

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

In view of this, HHI is researching novel possibilities for offering citizen services at different and changing locations by exploiting mobile/wireless networks and terminals. In particular, it has developed – together with a software company and two administrative districts of the city of Berlin as pilot users – a wireless system that can offer the same services that are available in a stationary office of citizen services. This system supports the entire work flow, from consultancy through application and payment to the final delivery of (hard) documents to the citizen (see Fig. 1). By means of the system, also sensitive personal data can be transferred via a wireless interface (GPRS, WLAN, UMTS). Hence, special emphasis is put on a secure connection (VPN based on IPsec).

Mobile offices of citizen services will be present in residential homes for the elderly, in hospitals, in shopping malls, at weekly markets, etc. Besides being more citizen-friendly, those mobile (or "nomadic") offices are expected to be more efficient, as they do not require such high rental fees and maintenance costs as stationary offices. Especially in large administrative districts they will offer a new quality of public service by "taking the office/service to the citizen".

After establishing and testing a secure wireless connection a field/pilot trial has started in two hospitals in Berlin. Within the framework of that trial, an "office for citizen services case", developed at HHI, is used and tested, which contains all components required for mobile citizen services (notebook computer, printer, network interface, etc.) in an ergonomically sound arrangement (see Fig. 2).



Fig. 2: A prototype of a "mobile office for citizen services case"

Before using the case in the trial, the equipment's usability was tested in a user test, in which citizen consultants acted as test subjects.

In spring 2004, the field trial will be broadened to more test sites (approx. eight) and a more detailed data collection will be applied.

After the end of the test period, the system will be applicable as an all-purpose system for wireless citizen services. Among other things, its employment is expected as being particularly beneficial in sparsely populated regions (e.g. rural areas) and/or locations with no stationary telecommunications network (e.g. developing countries).

This work is supported by the Federal Ministry of Economics and Labour of the Federal Republic of Germany (BMWA) under grant 01 MD 226.

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TOWARDS SEMANTIC SEARCH IN LARGE IMAGE DATABASES

We have developed a new method of representing and measuring the similarity of digital images without applying textual annotations. The user has the possibility to search for whole images or selected image parts.

Eine neue Form der Repräsentation und Ähnlichkeitsmessung digitaler Bilder ohne Textbeschreibungen wurde entwickelt, die dem Nutzer das automatische Suchen von Bildern oder Objekten in Bildern gestattet.

The number of people producing and storing multimedia data in digital way increases from year to year. Such data include text documents (doc, html), videos (DVD, mini-DV, DVB-T), audios (mp3) and still images (digi-cam, jpg). Hence, new requirements awake. People want to search for similar pieces of music, they want to find images showing persons (e.g. where grandma is sitting) or they want to cut all scenes with advertising automatically from a recorded movie.

Intelligent tools are required, in order to analyze the information and create the metadata (the “bits about the bits”), search specified pieces of information, and adequately represent the retrieval results. Considerable research efforts at Fraunhofer HHI have focused on the development of such tools.

A common representation of visual image properties are feature vectors which describe the color, texture, and edge statistics of the whole image. Images are considered as more similar, if the Euclidean distance between their feature vectors is smaller. Fig. 1 shows a typical result of such a search request. The first image is the query image. The following are retrieval results. The retrieval is fast, but the results are not satisfying.



Fig. 1: Poor results of a classical search request.
The first image is the query image

We have developed a new graph-based similarity measure for the comparison of images or parts of images.

For this purpose, the images are segmented automatically on various levels of detail into parts, which are homogeneous with respect to the color, edge and texture properties.



Fig. 2: An automatically segmented image

After hierarchical image segmentation, a graph describes the visual properties of image segments with MPEG-7 descriptors. Moreover, it includes information about their relative mutual positions within the various levels of the hierarchy (topology) and their relative mutual positions across the levels of the hierarchy (the vertical structure in Fig. 3).

This description graph is the basis of a fast recognition procedure. The procedure uses a special Neuronal Net for computing a graph metric in strict mathematical sense. This graph metric considers the visual properties of image segments as well as their relative mutual positions. A part-whole-decomposition of the description graph accelerates retrieval. Fig. 4 shows the results of a search request with our new approach. The search object is the labeled farmer.



Fig. 3: Graph representation of a hierarchically segmented image (hierarchy with 3 levels of detail)

The picture on the right has another background than the query image. The position of the farmer has shifted, in addition. Nevertheless the system is able to detect the farmer in all three images. The high similarity of search results is caused by the proposed graph representation and graph metric.



Fig. 4: Results of a search request (the labeled farmer) with our new approach

Computation time depends on the order of graph representation and the number of images in the database. With a database containing 100 images, a request for the farmer labeled in the left image in Fig. 4 needs 10 seconds computation time on a P4/2.4 GHz PC.

Our approach may be used as a plugin for classical image search engines, in order to improve the retrieval quality.

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MPEG-7 BASED ARCHIVING AND RETRIEVAL OF DIGITAL VIDEO

A new video asset management system is developed, which is capable of considerably simplifying the handling of and retrieval from large sized video databases, suitable for professional users, but also for home users. The core technology used for this approach is based on descriptions of audio and video data derived from the MPEG-7 standard, which is strictly applied. Further features are an intuitive video-summarization and a fast similarity search of videoshots.

Es wird ein neuartiges Videoarchivierungssystem entwickelt, das professionellen Nutzern – aber auch Nutzern von digitalem Video im Heimbereich – die effiziente Sichtung und Nutzung von großen Video-Datenbanken wesentlich vereinfacht. Als grundlegende Basis des Vorhabens werden an den MPEG-7 Standard angelehnte Beschreibungen von Ton- und Bilddaten genutzt, um Videoarchivierung möglichst standardkonform zu gestalten. Weitere Merkmale sind eine intuitive Videozusammenfassung und eine schnelle Suche nach ähnlichen Videoshots.

In recent years, the size of digital video archives has grown enormously. In particular, news agencies, TV broadcasters, and advertising agencies run large digital archives of movies and video footage. Furthermore, in the course of using digital technology, home users also pile up huge amounts of video data. With the size of archives growing, the problem of actually locating certain sequences becomes more and more challenging. Crucial for the success of most video asset management systems, both in the professional and the home user applications domain, will be the intuitive, efficient, and straightforward possibility to sift through and manage large quantities of video data.



Fig. 1: Screenshot of the video management system

A new video asset management system is under development, which is capable of considerably simplifying the handling of and retrieval from large sized video databases, suitable for professional users, but also for home users.

Automatic analysis procedures decompose the video sequence in its components, the shots. For this, a very fast method directly making use of the MPEG-2 encoded data stream was developed. Each shot is represented by a keyframe. The frames are shown in a storyboard. Each shot is described by its audio characteristics as well its color-, texture-, and motion features. The syntax of the used descriptors is defined in the MPEG-7 standard. These descriptors provide the low-level information for intuitive searches.

Videos, single shots or video segments can be displayed using a video-player (top right in Fig. 1). The storyboard presents the keyframe of each single shot. The contents of the shots can be browsed in fast motion using a slider. The displayed timeline shows the chronology of shots and their properties.

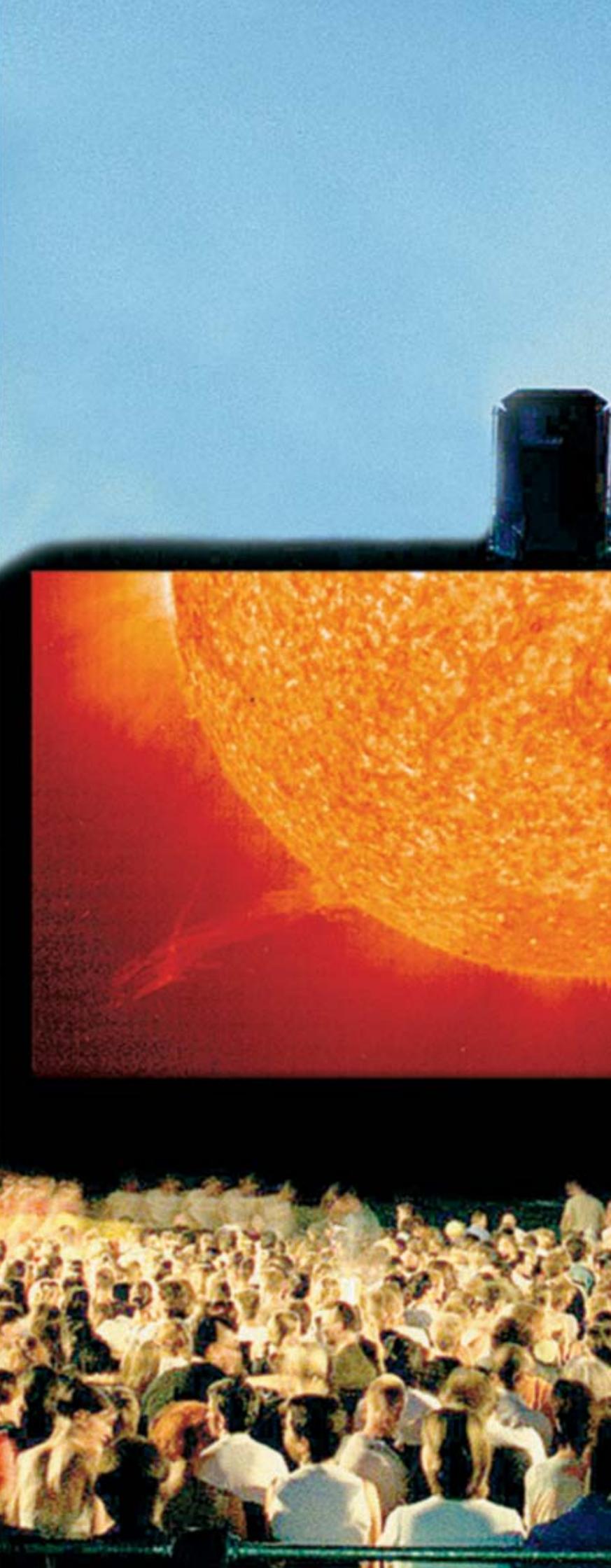
A new feature of this system is the possibility to search for similar shots using an example image. Many video segments, e.g. the weather forecast or the beginning of a newscast are characterized by typical contents. These contents can be stored as references and learned by the system. With the help of similarity searches previously “learned” video segments can be located and played back within a split second.

The system is developed in a joint project currently conducted in cooperation with Berlin University of Technology and Canto GmbH.

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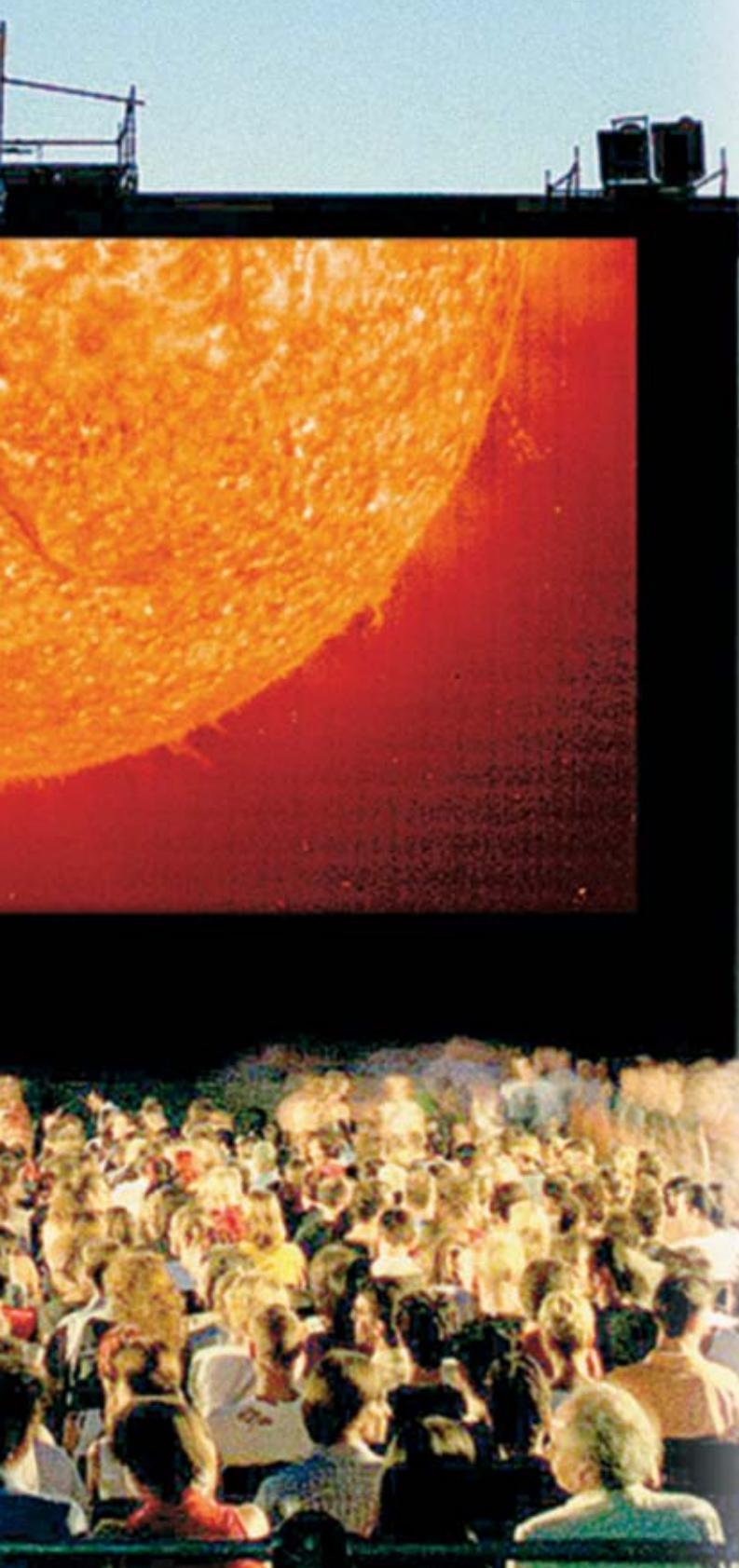


Image Processing

Information Technology (IT) is the driving force behind the Information Society of the 3rd millennium. IT is penetrating into almost all business areas and as well as into the private sector. Digital technologies help people in their businesses and private affairs, and digital technologies are more and more used to entertain people.

Multimedia is one of the key elements in Information Technology, because video, images, speech, sound and ancillary data are needed for an increasing number of services in the office, at home and in public areas.

The vision of **Multimedia services available for everybody at any time and any place** is the driving force behind the R&D developments of the Image Processing Department. It has built up key competencies and an internationally recognized reputation in the following areas:

- Image and video coding
- 3D image and video processing
- Image and video analysis, computer vision
- Image and video synthesis, computer graphics
- Multimedia transmission (IP, mobile, DVB)
- Hardware design and implementation of multimedia systems (video, audio, graphics)
- ASIC and IP design
- Image and video enhancement

One of the main activities in 2003 was the completion of the video coding standard H.264/AVC. Dr. Thomas Wiegand of HHI, who is co-chair of the Joint Video Team (JVT), a common activity of ISO/MPEG (Moving Pictures Experts Group) and ITU-T/VCEG (Video Coding Experts Group) developing H.264/AVC, acted as the editor of this standard. In addition, he also became the editor of DVB extensions (DVB-AVC) regarding H.264/AVC. Moreover, HHI continued to integrate and support the official H.264/AVC reference software of MPEG and VCEG.

Besides the standardisation activities, HHI developed its own software implementations of H.264/AVC which are highly optimised and offer an outstanding rate-distortion performance.

In addition, we developed an open multimedia streaming architecture based on H.264/AVC. This includes competitive rate-distortion performance against all existing multimedia streaming solutions and high packet loss resilience due to rate switching and scalable coding.



A third activity in this area focuses on the development of architectures for H.264/AVC coders and decoders for different applications. Examples are low power codecs for mobile devices and single chip decoders for TV and HDTV applications.

With these activities combined, HHI can offer to its customers a wide portfolio in compression technologies ranging from software implementations over hardware architectures to complete transmission systems and a number of applications such as wireless and wired video streaming or video surveillance.

Computer graphics and image processing technologies have reached a state that allows the development of novel multimedia applications and services. The new challenge in the field of television, electronic cinema and multimedia is called immersive telepresence, by which users should feel that they are immersed in the scene. Large displays with high resolution similar to cinema, IMAX or CAVE projections in VR applications are required. In this context, the current activities of the Image Processing Department are concentrated on four major applications: 3D videoconferencing, Digital Cinema, ultra-high resolution projection systems and 3D-TV.

Two other important topics are conversion from one video format to another (e.g. TV to HDTV) and image enhancement techniques (e.g. noise reduction). In the field of format conversion, HHI has established benchmark-setting know-how and expertise in numerous research activities. The developed motion-compensating video conversion algorithm (HiCON) provides a high quality conversion among different image sequence formats. It performs de-interlacing whilst preserving full spatial resolution. Image rate conversion is accomplished with good motion portrayal as it is required in high-quality image applications like digital cinema or optimised flicker-free and judder-free operation of high-end displays. HHI performed architectural studies on the basis of the HiCON techniques. Two different implementations have been developed – a commercial software solution (HiCON32) and an IP for a single chip (FPGA or ASIC) hardware solution. These technologies are of special interest with respect to the recently increasing market of High Definition Television.

3D modelling of objects, persons or head and shoulders is now a mature technology allowing the development of new services. Thanks to 3-dimensional computer models, video clips can be transmitted to mobile phones or pocket PCs even over low speed network connections. A mobile phone or PDA display may show the face of the person on the other end of the line – smiling, laughing or frowning in response to the last spoken words. This technology has

been used to develop an advanced video conferencing system using MPEG-4 that targets high quality encoding of head and shoulder image sequences at bit-rates of about 1 kbit/s. 3D head shoulder computer models are used to represent the person in the scene. MPEG-4 specifies animation parameters, which define temporal changes of facial expressions. The semantic representation simplifies the interaction and modification of the scene content. The low bit-rate enables the creation of facial animation on mobile phones or PDAs, which are connected to the Internet via low-bandwidth wireless channels such as GSM. A typical example is the conversion of the text SMS into animated video accompanied by generated voice in an MMS.

Besides video phone services, this technology enables other applications such as efficient streaming of newscasts and other animations as well as the realisations of user friendly computer interfaces or virtual agents.



Bildsignalverarbeitung

Die Informationstechnologie (IT) ist die treibende Kraft hinter der Informationsgesellschaft, IT zieht in fast alle Gesellschaftsbereiche, die geschäftlichen und in die privaten ein. Digitale Technologien unterstützen uns im Beruf und zu Hause und tragen immer mehr zu unserer Unterhaltung bei.

Multimedia ist eine der Schlüsselkomponenten in der Informationstechnologie, da Bilder, Video, Sprache, Ton und Zusatzdaten für eine steigende Zahl von Diensten im Büro, im Haushalt und in öffentlichen Bereichen verwendet werden.

Die Vision **Multimedia-Dienste für jeden an jedem Ort und zu jeder Zeit** ist auch die treibende Kraft hinter den F&E-Aktivitäten der Abteilung Bildsignalverarbeitung. Diese hat Kernkompetenzen und international anerkannte Reputation in den folgenden Bereichen aufgebaut bzw. erlangt:

- Bild- und Videocodierung
- 3D-Bild- und Videoverarbeitung
- Bild- und Videoanalyse, Computer Vision
- Bild- und Videosynthese, Computer-Grafik
- Multimedia-Übertragung (IP, mobil, DVB)
- Hardware-Entwurf und Implementierung von Multimedia-Systemen (Video, Audio, Grafik)
- ASIC- und IP-Design
- Bild- und Videoverbesserung

Eine der Hauptaktivitäten in 2003 war der Abschluss des neuen Videocodier-Standards H.264/AVC. Dr. Thomas Wiegand, der Co-Chair des Joint Video Teams (JVT) ist, einer gemeinsamen Aktivität von ISO/MPEG (Moving Pictures Experts Group) und ITU-T/VCEG (Video Coding Experts Group), die H.264/AVC entwickelte, war gleichzeitig Editor dieses Standards. Zusätzlich wurde er auch Editor von DVB-Erweiterungen (DVB-AVC) in Bezug auf H.264/AVC. Das HHI war darüber hinaus weiterhin mit der Integration und dem Support der offiziellen H.264/AVC Referenz-Software von MPEG und VCEG betraut.

Neben den Standardierungsaktivitäten hat das HHI eigene Software-Lösungen von H.264/AVC entwickelt, die hoch optimiert sind und eine herausragende Rate/Distortion-Performanz bieten. Zusätzlich wurde eine offene Multimedia-Streaming-Architektur, die auf H.264/AVC basiert, entwickelt. Dies schließt neben der exzellenten Rate/Distortion-Performanz auch eine Unanfälligkeit gegenüber Paketverlusten ein, die durch Datenratenumschaltung und skalierbare Codierung erreicht wird.

Eine dritte Aktivität in diesem Bereich betrifft die Entwicklung von Architekturen für H.264/AVC-Coder und Decoder für unterschiedliche Einsatzgebiete. Beispiele hierfür sind

Low-power-Codecs für mobile Endgeräte und Single-Chip-Decoder für TV- und HDTV-Anwendungen.

Mit diesen Aktivitäten kann das HHI seinen Kunden ein breites Portfolio an Codierungstechnologien bieten. Diese reichen von Software-Implementierungen über Hardware-Architekturen bis hin zu kompletten Übertragungssystemen und einer Anzahl von Anwendungen wie dem drahtlosen und drahtgebundenen Video-Streaming oder wie der Videoüberwachung.

Computer-Grafik und Bildverarbeitungstechnologien haben einen Stand erreicht, der die Entwicklung neuartiger Multimedia-Anwendungen und Dienste ermöglicht. Die neue Herausforderung in den Bereichen Fernsehen, elektronisches Kino und Multimedia heißt immersive Telepräsenz. Immersiv bedeutet in diesem Zusammenhang, dass der Nutzer das Gefühl hat, sich in der Szene zu befinden. Große Displays mit sehr hoher Auflösung, ähnlich wie im Kino, im IMAX oder bei CAVE-Projektionen in VR-Anwendungen werden hierfür benötigt. In diesem Kontext gibt es in der Abteilung Bildsignalverarbeitung vier Hauptaktivitäten: 3D-Videokonferenz, digitales Kino, ultra-hochauflösende Projektionssysteme und 3D-TV.

Zwei andere wichtige Forschungsfelder sind die Formatkonversion (z.B. TV nach HDTV) und die Bildverbesserung (z.B. Rauschreduktion). Im Bereich der Formatkonversion hat sich das HHI in zahlreichen Forschungsprojekten ein führendes Know-how erarbeitet. Der entwickelte bewegungskompensierende Videokonversionsalgorithmus (HiCON) bietet eine hochqualitative Wandlung zwischen verschiedenen Bildsequenzformaten. De-Interlacing kann ohne Verlust an örtlicher Auflösung durchgeführt werden, eine Bildtafelwandlung wird mit guter Bewegungswiedergabe durchgeführt, wie sie für hochqualitative Anwendungen wie digitales Kino oder flicker- und ruckelfreie Bilddarstellung auf High-end-Displays benötigt wird. Im HHI wurden Architekturstudien auf der Basis der HiCON-Techniken durchgeführt. Dabei wurden zwei verschiedene Implementierungen entwickelt, eine Software-Lösung (HiCON32), die als Produkt vermarktet wird, und ein IP für Single-Chip-Hardware-Lösungen (FPGA oder ASIC). Diese Technologien sind insbesondere für den sich nun endlich auch in Europa entwickelnden HD-Markt von besonderem Interesse.

Die 3D-Modellierung von Objekten, Personen oder Kopf- und Schulteransichten ist eine Technologie, die mittlerweile ihren Kinderschuhen entwachsen ist und nun die Entwicklung völlig neuer Dienste ermöglicht. Dank 3-dimensionaler Computer-Modelle können Videoclips mit extrem geringer Datensatz an Handys und Pocket-PCs übertragen werden. Das Display eines Mobiltelefons oder PDAs kann das Gesicht der Person am anderen Ende der Leitung in



Abhängigkeit von der übertragenden Sprache lächeln, lachen oder die Stirn runzeln lassen.

Am HHI wurde diese Technologie verwendet, um ein „Advanced Video Conferencing“ System unter Verwendung von MPEG-4 zu entwickeln. Dabei wird eine hochqualitative Codierung von Kopf-Schulter-Bildsequenzen mit Datenraten von ca. 1 kbit/s angestrebt. 3D-Modelle von Köpfen und Schultern werden verwendet, um Personen in Videoszenen zu repräsentieren. MPEG-4 spezifiziert dabei so genannte Animationsparameter, die zeitliche Änderungen des Gesichtsausdrucks spezifizieren. Diese semantische Repräsentation vereinfacht die Interaction und Modifikation des Szeneninhalts. Auf Grund der sehr geringen Bitrate wird damit eine Gesichtsanimation auf mobilen Terminals wie Handys oder PDAs auch über sehr schmalbandige mobile Kanäle wie GSM möglich. Ein typisches Beispiel hierfür ist die Transformation des Textes einer SMS in Sprache sowie in ein animiertes Video in Form einer MMS.

Neben Videotelefondiensten ermöglicht diese Technologie auch andere Anwendungen wie das effiziente Streaming von Nachrichten und anderer Animationen oder die Realisierung von nutzerfreundlichen Mensch-Maschine-Interfaces und virtuellen Agenten.



Image Processing

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Multi projection systems for Digital Cinema



Video codecs and streaming solutions for mobile communication



Video services and video based information systems in the vehicle



im.point: Immersive video conference system



IM.POINT – THE IMMERSIVE MEETING POINT

The im.point is a flexible human-centered immersive videoconferencing system realizing a shared virtual table approach with standard PC technology. Apart from the entire conference system, dedicated single components of 3D video processing are offered as SDK's e.g. for intermediate view rendering at autostereoscopic displays.

Der im.point ist ein flexibles, auf die menschlichen Kommunikationsbedürfnisse zugeschnittenes Videokonferenzsystem, welches einen „Shared Virtual Table“-Ansatz auf Standard-PC-Technologie realisiert. Abgesehen vom vollständigen Konferenzsystem sind auch Einzelkomponenten zur 3D Videoverarbeitung als SDKs erhältlich, um z.B. Zwischenansichten für autostereoskopische Displays zu generieren.

Although many commercial video conferencing systems already support tele-presence features, they are still impaired by a lack of realism in terms of body language, gestures, gaze direction and eye contact.



Fig. 1: im.point conferencing terminal

The concept of so-called „Shared Virtual Table Environment“ is a well-known approach to overcome these limitations. The idea is based on a mixed-reality set-up consisting of a table which is half real and half virtual (see Fig. 1). The latter is part of a shared virtual environment (SVE).

Two remote conferees from different locations are seamlessly integrated into the SVE and placed at well-defined positions around the virtual table.

The im.point system is the first prototype system that offers such a solution on basis of standard PC technology. The entire video processing is implemented in software and meets real-time requirements in full TV resolution. The geometric setup of the conferencing terminal together with the virtual scene and the 61" plasma display, which covers almost the whole field of view, lead to a conferencing system that provides active and passive eye contact as well as correct reproduction of body language, gestures and gaze direction. As a result, active conferees get the sensation of a face-to-face conversation whereas passive conferees can recognize who is talking to whom.

The whole system is extremely flexible in terms of configuration, mounting and transportation. One station can be disassembled, moved and reassembled in a few hours. A professional flightcase is able to carry the complete station for easy handling during shipping. A low end solution supporting all SVE features with limited video resolution can be run on a single PC with a standard monitor and two web cams. The high end system from Fig. 1 consists of three PCs, a 61" plasma display and four high quality cameras. It delivers full TV video resolution and utilises 3D video processing modules for the provision of real eye contact.

Video compression, scene representation and network interaction rely on the MPEG-4 standard. Video coding is able to cope with arbitrarily shaped video objects. BIFS of MPEG-4 is used for SVE scene description. Dynamic scene changes are achieved by BIFS-updates. Network interaction is based on the DMIF framework of MPEG-4.

As a side-effect, powerful 3D video processing tools, especially for disparity estimation and view synthesis, have been developed in this framework.

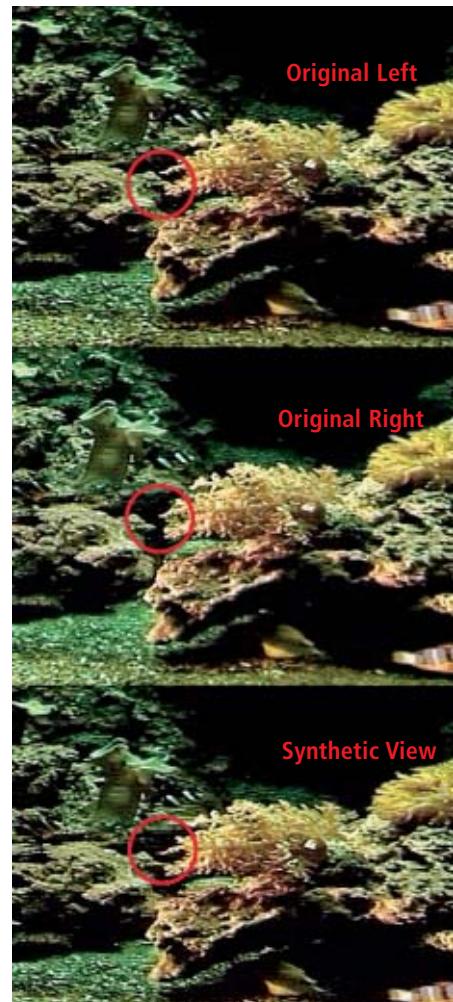


Fig. 2: View rendering for autostereoscopic displays

Due to the modular and professional software architecture, they can easily be extracted as SDK's and adapted to the needs of individual customers for various other applications.

For instance, an interesting application comes up with autostereoscopic multi-view displays where intermediate views have to be calculated from a regular stereo sequence. In this context an SDK for disparity estimation and view synthesis computing new views in realtime on a standard PC in TV resolution is under development.

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3D SCENE AND OBJECT RECONSTRUCTION FOR INTERACTIVE MULTIMEDIA SERVICES

Capturing real world scenes simultaneously with multiple cameras allows the reconstruction of dynamic 3D models. Such models enable free navigation within real world scenes, i.e. choosing arbitrary viewpoints. Virtual intermediate views can be rendered as it is known from computer graphics.

Die simultane Aufnahme realer Szenen mit mehreren Kameras ermöglicht die Rekonstruktion dynamischer 3D Modelle. Dies ermöglicht die freie Navigation innerhalb realer Szenen, d. h. die Auswahl beliebiger Standpunkte. Dazu werden virtuelle Zwischenansichten erzeugt, wie es bisher aus der Computer-Grafik bekannt ist.

Interactivity is an important key feature of audio-visual media applications. One type of interactivity is the ability to look around within a scene by freely choosing a viewpoint. The first representations that provided such functionality were based on textured 3D mesh models, well known from computer graphics, computer games and virtual reality.

Most of the scenes are either purely computer generated or contain static 2D views of real world objects. Recent achievements in image acquisition, processing, representation, and rendering also allow the user to navigate within dynamic real world scenes. Multiple cameras are used to capture such scenes. The acquired imagery is converted into a representation format that allows interactive rendering.

We present a system for 3D reconstruction of dynamic real world objects and scenes, flexible data representation, efficient coding, and interactive rendering. The scene is captured by multiple synchronized cameras.

First, the camera geometry is estimated in relation to a 3D world coordinate system (extrinsic and intrinsic camera parameters). Then the scene is segmented into objects using state-of-the-art computer vision algorithms for each view separately, resulting in silhouette images for each object in each view at each time. An object's 3D geometry is reconstructed from the silhouette images taking into account the knowledge about the camera geometry (shape-from-silhouette). The volume covered by the cameras is modelled using volume elements (voxels). Each voxel is projected into the silhouette images. Based on this algorithm, a decision can be taken whether it belongs to the object or not (space carving). In order to speed up processing, we perform voxel reconstruction in a hierarchical refinement process (octree) as illustrated in Fig. 1.

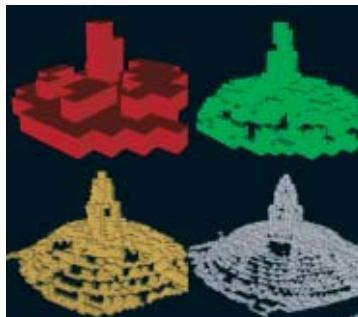


Fig. 1: Recursive refinement of voxel geometry

The result is a voxel model for each time instance that is converted into a classical 3D mesh model using a standard algorithm (marching cubes) as illustrated in Fig. 2. The reason is to benefit from advanced rendering software API's such as DirectX and to exploit the capabilities of today's efficient graphics hardware which is highly optimized for rendering of 3D meshes.

The extracted 3D model is then textured and coloured for interactive rendering by a weighted combination of the original views available from the cameras. For that we developed a view dependent multi texturing algorithm that approximates natural

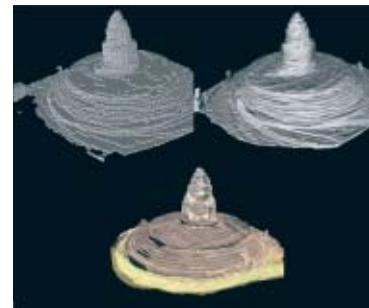


Fig. 2: Voxel, 3D mesh, and textured model

appearance when navigating through the scene from any position as far as possible. Fig. 2 shows and example of a rendered virtual view.

Interoperable exchange of such data between different systems requires standardized and efficient formats. Our solution is fully compatible to MPEG-4. The 3D geometry is coded using SNHC tools. The corresponding video textures are coded using H.264/AVC. Our algorithms for view-dependent texture mapping have been adopted as an extension of MPEG-4 AFX.

Such a reconstructed 3D video object can be rendered for any viewpoint and direction. Fig. 3 illustrates the functionality provided by our system. It shows snapshots of a virtual camera fly around a 3D video object while it is moving, for 4 different viewpoints at 4 different times. This also allows easy production of special effects such as stop-motion effects known from recent movies (e.g. Matrix).

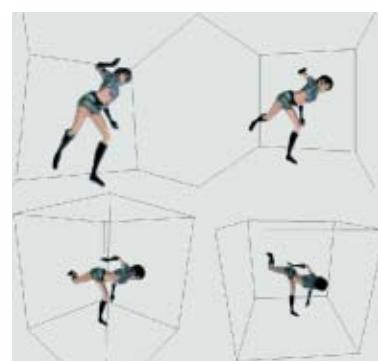


Fig. 3: Virtual camera fly, rendered views at 4 times instances from 4 virtual viewpoints

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EMBEDDED SOFTWARE SOLUTIONS FOR VIDEO PROCESSORS IN MOBILE PHONES

Modern multimedia applications like audio-visual coding require a high amount of computational power and memory space, which in general does not cause problems for platforms like PCs or Laptops. However, most mobile terminals like PDAs or cellular video phones are built around embedded processors, which underlie severe restrictions concerning computing power and memory usage. Therefore specialized software components, optimized for embedded processors have been developed.

Moderne Multimedia-Anwendungen wie die Audio- und Videocodierung stellen sehr hohe Anforderungen an Rechenleistung und Speicherbedarf, was auf Plattformen wie PCs und Laptops kein Problem darstellt. Dagegen werden mobile Endgeräte wie PDAs und Mobiltelefone zumeist auf Basis von eingebetteten Prozessoren realisiert, die starken Restriktionen hinsichtlich Rechenleistung und Speichergröße unterliegen. Daher wurden spezielle, optimierte Softwarekomponenten für eingebettete Prozessoren entwickelt.



Fig.: Typical target platforms for optimized embedded software

Current embedded multimedia applications, such as MPEG-4 or H.264/ AVC video codecs, are more and more implemented as processor based systems. Embedded processors in conjunction with hardware accelerators fulfil the arithmetic requirements of such codecs. However, the major problems concerning performance and power consump-

tion emerges from the huge amount of data to be transferred in these applications. This problem is even increased if the given data bandwidth is not used efficiently.

In order to reduce the overall data traffic, those parts of the code, which require a high amount of data transfer, have to be identified and optimized. However, since the software of the above mentioned applications may contain up to 100.000 lines of code, tools are required, which help the designer to identify those critical parts. Several analysis tools for such applications already exist: Time analysis is provided by profiling tools such as gprof¹ or VTune². Memory access analysis is part of the ATOMIUM³ tool suite. ATOMIUM performs this analysis based on source code extended by an instrumentation code. However, all these tools provide only approximate results for either timing or memory accesses. Therefore an alternate way to perform highly accurate memory analysis is to trace the memory interface of the processor. This can be done with a VHDL simulator, if a VHDL model of the processor is available, but it implies long simulation times.

In order to achieve faster solutions, a specialized tool, called memtrace, has been developed at HHI, which works in a similar way, but uses the cycle-accurate processor emulator ARMulator of ARM Ltd. This emulator is software-based and cycle-accurate. This allows memtrace to provide highly accurate results in a moderate simulation time. However it restricts the results to software, which is dedicated to processors of the ARM family, the most used embedded processor architecture of today's market.

Nevertheless, memtrace provides the user with a per-function analysis of memory accesses and timing. Therefore, by using this special memory profiling technique it is possible to analyze and optimize platform independent C-code implementations.

In order to prove this concept, a MPEG-4 video codec has been ported for the ARM9 processor architecture. The codec has been optimized in terms of needed computational power, required memory space and number of memory accesses/memory bandwidth. All software optimizations could be realized using C-code instead of assembly language constructs, which are hard to maintain. For real time optimizations, well known strategies like loop unrolling, using shift operations instead of multiplications and avoidance of divisions have been applied. To reduce the memory bandwidth, the code was optimized using the achieved profiling runs performed with memtrace and the ARM Armulator simulation environment. The results show that the usage of data elements stored in structures, which reside in the main memory instead of using local variables, leads to a much higher memory bandwidth than needed.

The whole software has been revised to avoid multi memory accesses to the same data element, instead of using a single local variable. Using the mentioned techniques, the overall performance of decoder and encoder has been doubled in terms of processing speed.

For encoding and decoding the required memory size is about 24 kByte of data memory and 30 kByte of program memory exclusive the needed frame memory which depends on the used picture resolution. Based on the described software development and optimization approach, MPEG-4, H.264/AVC and H.263 codecs could be implemented on several embedded processors.

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1 <http://www.gnu.org/manual/gprof/>

2 <http://www.intel.com/software/products/vtune/>

3 J. Bormans, et.al., "Integrating System-Level Low Power Methodologies into a Real-Life Design Flow", Proceedings of PATMOS'99, October 6-8, 1999, pp. 19-28.



FACIAL ANIMATION FOR MOBILE SERVICES

3D face models as described in MPEG-4 combined with 3D image analysis technology developed at the HHI enable new applications for mobile services like video streaming at bit-rates of a few kbit/s, intelligent user interfaces, or animated text messages on mobile phones.

3D-Kopfmodelle, wie in MPEG-4 spezifiziert, eröffnen in Kombination mit der am HHI entwickelten 3D Bildanalysetechnologie neuartige Anwendungen wie beispielsweise Videoübertragung bei Datenraten von wenigen kbit/s, intelligente Computerschnittstellen oder animierte Textnachrichten für Mobiltelefone.

Handheld devices like mobile phones or personal digital assistants (PDA's) offer more and more functionality. Beside the simple phone conversation, new services in many different application areas are currently launched. The devices are equipped with cameras for image or video capture and services like the Multimedia Message Service (MMS) simplify the exchange of videos or other multimedia content. The transmission of high quality video, however, requires high bit-rates which cannot be guaranteed by all wireless channels, especially if many users have to share the same cell. At the FhG-HHI, we have developed a new model-based coding technique that allows video streaming of head-and-shoulder sequences at bit-rates of a few kbit/s using MPEG-4 facial animation technology. Beside the low bit-rate, the algorithms for facial expression analysis and synthesis can be exploited in many different applications. User-friendly computer interfaces, avatar control on websites, animated text messages, motion capture for character animation in film production, and medical solutions for guidance in therapy or diagnosis are just some examples.



Fig. 1: Real-time facial animation on a PDA

For video streaming, the facial animation framework is used to efficiently represent the scene content. In contrast to current hybrid video codecs, we describe the scene content by textured 3D computer models. For head-and-shoulder video sequences, a 3D head model describes the appearance of the person in the video. This model is transmitted only once. Temporal changes are described by 3D motion and facial mimic parameters according to the MPEG-4 standard. These facial animation parameters (FAP's) describe the deformation in the face due to facial expressions and are estimated from the video at the encoder. Since only few parameters have to be transmitted, bit-rates of about 1 kbit/s can be achieved. At the decoder, the head model is deformed according to these values and the video is synthesized using computer graphics techniques. The computational complexity at the decoder is quite low, enabling realtime rendering even on mobile devices as shown in Fig. 1.



Fig. 2: Facial animation for car entertainment and user-friendly interfaces

The explicit knowledge of 3D shape and facial mimic information add new features to the simple video transmission. For example, the head model can be replaced in order to animate other people or cartoons with the facial play of an actor as shown in Fig. 3. Such motion capture techniques can help to revive artificial characters in film productions or enhance computer games.



Fig. 3: Animation of arbitrary people or cartoons from video input

Facial mimic cannot only be derived from video input. There is also a strong correlation between lip motion and the text that is spoken by the person. At the FhG-HHI, we have developed a system for the automatic creation of short animations from simple text messages. Beside the simple e-card service, we target the creation of MMS videos in mobile phone environment. A user sends a SMS to a provider. There, a text-to-speech server creates synthetic voice as well as an artificial animation of a chosen character that is synchronized with the speech signal. The recipient finally obtains a MMS with your favorite person reading the message.



Fig. 4: Automatic creation of fun animations from simple SMS messages

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ADAPTIVE MULTIMEDIA STREAMING USING H.264/AVC

The real time delivery of coded audio and video data over the Internet is becoming increasingly important. Presently common systems are proprietary and insufficient. The solution of FHG-HHI is aimed at achieving high video and audio quality also at variation in network resources. Our solution is completely based on open standards.

Die Verbreitung audiovisueller Daten über das Internet wird zunehmend wichtig. Die derzeit verbreiteten Systeme bieten allerdings nur proprietäre und meist ungenügende Lösungen. Das von uns entwickelte Streamingsystem erreicht eine deutlich verbesserte Qualität bei schwankenden Netzwerk-Ressourcen und basiert ausschließlich auf offenen Standards.

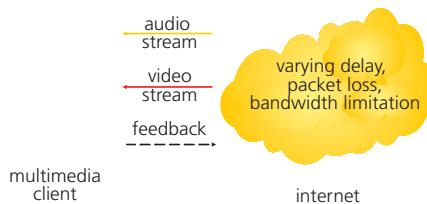


Fig. 1: Adaptive Multimedia Internet Streaming System

The importance of delivering multimedia data over IP networks will steadily grow. However a continuous transmission (=streaming) of multimedia data over the Internet creates new challenges. One key problem is the adjustment of the media data rate to the available network capacity.

The Fraunhofer Institute for Telecommunications – Heinrich Hertz Institute (HHI) used its leading video coding technology to develop a new multimedia streaming solution as shown in Fig. 1. This solution is aimed at achieving multimedia streaming at TV broadcast quality. Based on the open speci-

fication of the Internet Engineering Task Force (IETF) and the Internet Streaming Media Alliance (ISMA), this streaming media solution offers the additional benefit of robustness against data rate variations and packet loss by utilizing scalable and switchable approaches.

The emerging open standards H.264/AVC and the MPEG4-AAC have been integrated into the real time streaming solution. H.264/AVC has been jointly developed by the Video Coding Expert Group (VCEG) of the International Telecommunication Union (ITU-T) and the Moving Pictures Expert Group (MPEG) of the International Standard Organization (ISO). The new video coding standard to which HHI contributed significantly, provides a considerable improvement in coding efficiency as well as new features for network-friendly transmission.

supporting MPEG-4 video as well as MPEG-4-AAC and additionally the new features of H.264/AVC. The client also supports the Real Time Protocol (RTP) with reliable extensions like feedback and retransmission. Furthermore, a Streaming Server, that uses the MP4- and AVC-file formats as media container format, is integrated into the system. The AVC-file format provides additional information about frame priority, frame dependency and switchable frames.



Fig. 2: Error propagation caused by video packet loss in case of variation in network capacity



Fig. 3: Error free frame using video rate adaptation techniques

The solution comprises an important feature: video rate adaptation for stored media data. In case of variation in network capacity, the video sending rate has to be adapted to the available network data rate, otherwise packet loss can occur. Such an uncontrolled loss of a video packet can cause error propagation in the video decoding process as shown in Fig. 2. Using rate adaptation techniques like bitstream switching and temporal scaling can avoid such losses and significantly enhance the video quality as shown in Fig. 3.

Moreover the solution consists of an ISMA compliant multimedia client

Depending on the current available network capacity and the expected client buffer delay, the server uses this information to scale the video stream temporally and/or to switch between pre-encoded video streams at different data rates.

The server achieves a possibly required data rate reduction by starting with frame dropping of low priority frames and by moving to the next lower quality level. If better network condition is detected by probing for new available data-rate, the server switches to a higher quality level.

The network condition is measured by using feedback information provided by the Real Time Control Protocol (RTCP).

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A DVB COMPLIANT 3D-TV SYSTEM

It is widely expected that 3D-TV will be the next revolutionary step in the history of television. Against this technical background the European IST project ATTEST has developed a new DVB compliant system architecture for 3D-TV. It is based on a novel data representation format providing a number of features that are essential for successfully bringing 3D-TV onto the market.

Es ist weit verbreite Ansicht, dass 3D-TV den nächsten großen Entwicklungsschritt in der Fernsehgeschichte darstellen wird. Vor diesem technischen Hintergrund hat das Europäische IST-Projekt ATTEST eine neue DVB-konforme Systemarchitektur für 3D-TV vorgeschlagen. Sie basiert auf einem neuen Datenrepräsentationsformat, das eine Reihe von Leistungsmerkmalen bietet, die für eine erfolgreiche Markteinführung essentiell sind.

Former 3D-TV proposals often relied on the basic concept of "stereoscopic" video, i.e. the capturing, transmission and display of two separate video streams – one for the left eye and one for the right eye. In contrast, the ATTEST system uses a two-layered data representation format with a baseline layer of monoscopic color video and a supplementary layer of per-pixel depth information (see Fig. 1). Both layers are transmitted in a single program as separate, synchronized streams.



Fig. 1: The data representation format consisting of monoscopic color video and associated 8-bit per-pixel depth information

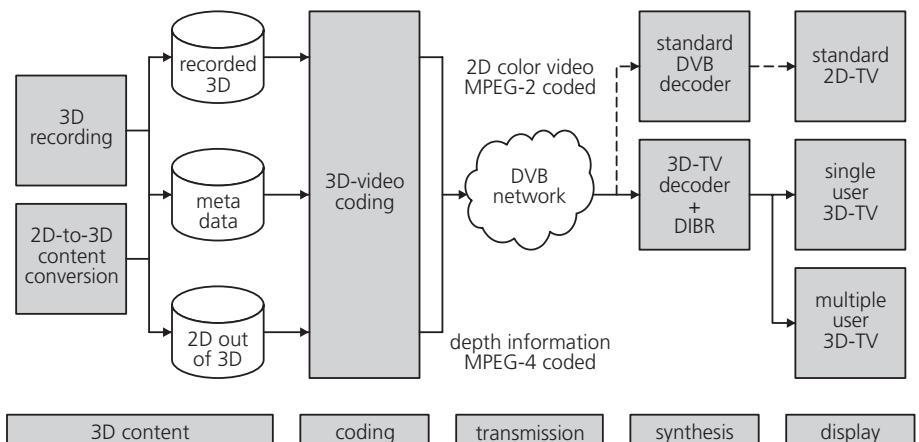
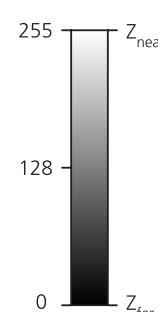


Fig. 2: The signal processing and data transmission chain of the ATTEST project

From this data representation, "virtual" stereoscopic views can be generated in real-time at the receiver side by means of so-called depth-image-based rendering (DIBR) techniques. This gives the user the opportunity to adapt the 3D representation to particular properties of his receiver as well as to his very individual taste of depth sensation (similar to individual color adjustment in today's 2D color TV sets). Moreover, backwards compatibility to standard TV receivers is simply achieved by decoding the baseline layer only.

Fig. 2 shows the envisioned signal processing and data transmission chain of the whole ATTEST concept. It consists of five different functional building blocks:

- 1) 3D content creation;
- 2) video coding;
- 3) transmission;
- 4) "virtual" view synthesis;
- 5) 3D display.



The 3D content is generated either by capturing video and depth jointly with an active Z-range camera or by converting already existing 2D video material into 3D using so-called "structure from motion" algorithms. To transmit this data in a DVB compliant way, the baseline color video layer is encoded with MPEG-2, while the supplementary depth-images are compressed using Advanced Video Coding (AVC).

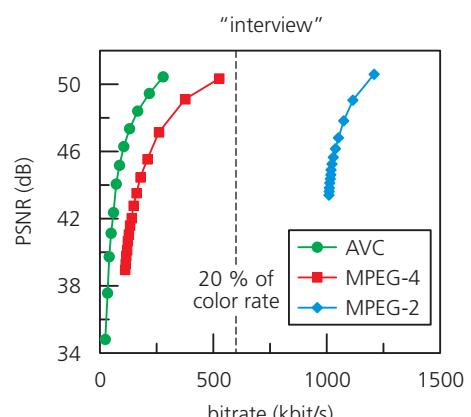


Fig. 3: Rate-distortion results for the compression of per-pixel depth information

As shown in Fig. 3, this most recent addition to the MPEG family of standards makes coding of per-pixel depth information extremely efficient. Compared to today's digital 2D-TV the transmission overhead for the supplementary depth layer is 10–20% or even less.

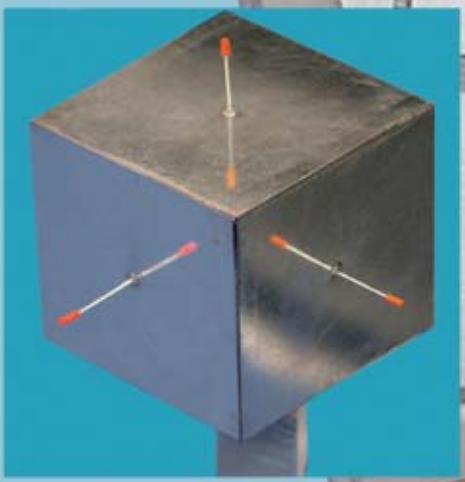
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Multi-Antenna techniques for GBit/s wireless

MIMO = 4 in

many parallel data lines
in one WLAN card
by spatial multiplexing

SONY





Broadband Mobile Systems

Mobile communication has become part of our daily life. Cellular phones are more or less everyday life utensils, which increasingly take over more functions. Beside GSM (2G) or UMTS (3G) which offer full coverage but need a quite expensive infrastructure, wireless local area networks (WLAN) emerged increasingly for wireless networking of computers and for wireless internet access.

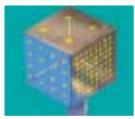
In the year 2002 the number of cellular subscribers worldwide exceeded for the first time those of the land line subscribers. A similar development is predicted for the year 2005 for the wireless internet access. The WLAN market has an enormous growth potential, in particular if hot-spot areas e.g. airports, stations, areas of companies and universities are made accessible to more users with higher data rates.

MIMO (multiple input multiple output) is a promising technological approach for next generation systems (4G) with a high data throughput, since due to the spatial multiplexing the spectral efficiency is drastically increased. The base station and all mobile terminals each have several antennas and transmit within the same frequency band different data streams in parallel. In brief, the system capacity increases linearly with the number of the transmitter and receiver antenna pairs if the radio channel has appropriate degrees of freedom. This is exactly the case in urban areas and inside of buildings due to their physical characteristics, thus exactly there where this technology is to be used.

Except for applying new techniques, e.g. MIMO, the efficiency of mobile communication systems can also be increased by a cross-layer optimization of protocols. A large potential lies within an adaptive transmission control (voice and data) depending on the actual channel quality. For this purpose the transmission has to be optimised over the entire multiple access channel and not only over a single user connection alone.

The department of broadband mobile communication systems develops solutions within the entire range from the theory about channel measurements, design of detection algorithms, system simulations up to the implementation of algorithms in the demonstrator with the following emphasis:

1. WLAN und Hot Spot Areas
 - MIMO-OFDM Systems
 - GBit Systems (60 GHz und MIMO)
 - Adaptive Modulation and Coding



2. System design aspects of future cellular systems
 - Multiple access techniques
 - Feedback channels
3. Real time demonstrators
 - MIMO and Multi user aspects @ 5 GHz
 - GBit/s transmission techniques @ 60 GHz

The experimental validation in a test-bed can determine the actual gain of particular algorithms or procedures under realistic conditions such as temporally variable channels.

These results are vital for the continued improvement of our systems.

Breitband Mobilfunknetze

Die Mobilkommunikation hat in vielen Teilen unseres Lebens Einzug gehalten, das Handy ist ein Alltagsgebrauchsgegenstand geworden, der zunehmend mehr Funktionen übernimmt. Innerhalb der letzten Jahre hat sich unabhängig von den flächendeckenden - und damit relativ teuren - Mobilkommunikationsnetzen wie GSM (2G) oder UMTS (3G) die WLAN (wireless local area network) Technik für die drahtlose Vernetzung von Rechnern und den drahtlosen Internetzugang entwickelt.

Im Jahr 2002 hat die Anzahl der Mobilfunkteilnehmer erstmalig weltweit die der drahtgebundenen Anschlüsse übertroffen. Für den drahtlosen Internetzugang ist eine ähnliche Entwicklung für das Jahr 2005 prognostiziert. Der WLAN Markt hat also ein enormes Wachstumspotential, insbesondere dann, wenn es zusätzlich gelingt in so genannten Hot Spot Areas wie z.B. Flughäfen, Bahnhöfen, Geländen von Firmen und Universitäten, etc. aber auch z.B. entlang stark befahrener Straßen einer Vielzahl von Teilnehmern höhere Datenraten zugänglich zu machen.

MIMO (multiple input multiple output) ist eine viel versprechende Technik für Systeme der nächsten Generation (4G) mit hohem Datendurchsatz, da aufgrund des räumlichen Multiplex die spektrale Effizienz drastisch erhöht wird. Hierbei verfügen Basis- und Mobilstation jeweils über mehrere Antennen und übertragen innerhalb desselben Frequenzbandes parallel unterschiedliche Datenströme. Vereinfacht dargestellt erhöht sich die Systemkapazität linear mit der Anzahl der Sende- und Empfangsantennenpaare, wenn der Funkkanal entsprechende Freiheitsgrade aufweist. Aufgrund der physikalischen Eigenschaften ist das genau der Fall in urbanen Gebieten und im Inneren von Gebäuden, also genau dort, wo diese Technik eingesetzt werden soll.

Außer durch Einsatz neuer Techniken wie z.B. MIMO lässt sich die Effizienz von Mobilkommunikationssystemen noch steigern durch eine schichtübergreifende Optimierung der Protokolle. Hier liegt ein großes Potential in der Steuerung der Übertragung (Sprache und Daten) in Abhängigkeit von der Kanalqualität. Hierbei wird die Übertragung über den gesamten Vielfachzugriffskanal optimiert und nicht nur über die Einzelverbindung.

Die Abteilung Breitband Mobilfunknetze erarbeitet Lösungen innerhalb der gesamten Spanne von der Theorie über Kanalmessungen, Entwurf von Detektionsalgorithmen, Systemsimulationen bis hin zur Algorithmenimplementierung im Demonstrator mit folgenden Schwerpunkten:

1. WLAN und Hot Spot Areas
 - MIMO-OFDM Systeme
 - GBit Systeme (60 GHz und MIMO)
 - Adaptive Modulation und Codierung
2. Systemdesignaspekte zukünftiger zellularer Systeme
 - Vielfachzugriffsverfahren
 - Feedback Kanäle
3. Echtzeitdemonstratoren und Testbetten
 - MIMO und Multiuser Aspekte @ 5 GHz
 - GBit/s Übertragungsverfahren @ 60 GHz

Mit dem Nachweis im Testbett kann der tatsächliche Gewinn, den ein bestimmter Algorithmus bzw. ein bestimmtes Verfahren bringt, unter realistischen Bedingungen im zeitlich veränderlichen Kanal ermittelt werden. Die Ergebnisse ermöglichen uns die Systeme weiter zu verbessern.



Broadband Mobile Communication Networks

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MIMO (multiple input multiple output) techniques can quadruple the WLAN capacity



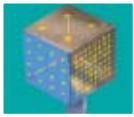
MIMO triple antenna @ 5.2 GHz



MIMO cube antenna used for channel measurements



Commercially available WLAN cards



OPTIMAL TRANSMISSION STRATEGY FOR THE MIMO MAC WITH MMSE RECEIVER

Future cellular wireless systems will apply multiple antennas at the base and the mobiles in order to increase throughput and reliability. If the base performs optimal linear detection the performance metric of the overall system is the normalised sum mean-square-error (MSE). We develop an efficient iterative algorithm which optimises the sum MSE of the overall system.

Zellulare Mobilfunksysteme der nächsten Generation werden Mehrantennensysteme an der Basisstation und an den mobilen Endgeräten einsetzen, um den Durchsatz und die Zuverlässigkeit zu erhöhen. Wird an der Basisstation der optimale lineare Empfänger verwandt, kann die Zuverlässigkeit des Gesamtsystems durch den normierten mittleren quadratischen Summenfehler (MSE) charakterisiert werden. Wir entwickeln einen effizienten iterativen Algorithmus, der den Summen-MSE des Gesamtsystems optimiert.

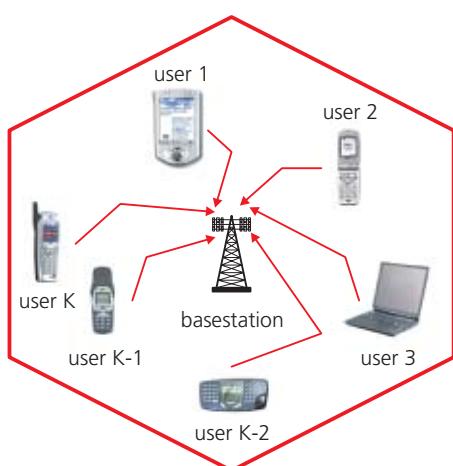


Fig. 1: Cellular wireless system:
Multiple antenna multiple access channel

In wireless point-to-point links, one applies multiple antennas to increase the spectral efficiency and the performance. On the other hand, in multi-user scenarios, multiple antennas at the

base or even at the mobiles require the development of new transmission strategies in order to achieve the benefits of using the spatial domain. In multiple input multiple output (MIMO) multiple access channels (MAC), the optimum transmission strategy depends on the objective function, the power constraints, the channel realisation, and the SNR range.

In general, the optimisation problems are divided into two classes: In the first one, the objective function measures the global performance criteria of the system. In order to increase the average throughput of the MIMO MAC, the sum capacity can be maximised or the average normalised MSE can be minimised. The other class of optimisation problems deals with the fulfilment of rate, SINR, or MSE requirements with minimal power. We are going to solve the sum performance optimisation problem. In order to simplify the analysis, it is of advantage to divide the programming problem into parts which can be solved in an iterative fashion.

Consider the multiple access channel in Fig. 1. Multiple users transmit their data at the same time and on the same frequency to one base station in the cell. The channel between each user and the base station is modelled by a block flat fading MIMO channel. We have K mobiles with n_T antennas each. We can easily extend the results to the case in which every mobile has a different number of transmit antennas. The base station owns n_R receive antennas. It is assumed that the base as well as the mobiles have perfect channel state information. The base station performs the optimal linear multi-user detection, i.e. MMSE detection. In order to maximise the cell throughput, the sum MSE is minimised under a sum power constraint on the transmit power.

The construction of the solution to the sum performance optimisation of multi-user MIMO systems is as follows: The original problem of transmit strategy optimisation is decomposed into two sub-problems, namely power allocation and covariance matrix optimisation under individual power constraints. The covariance matrix optimisation is separately performed for each user in an iterative fashion. This scheme is illustrated in Fig. 2.

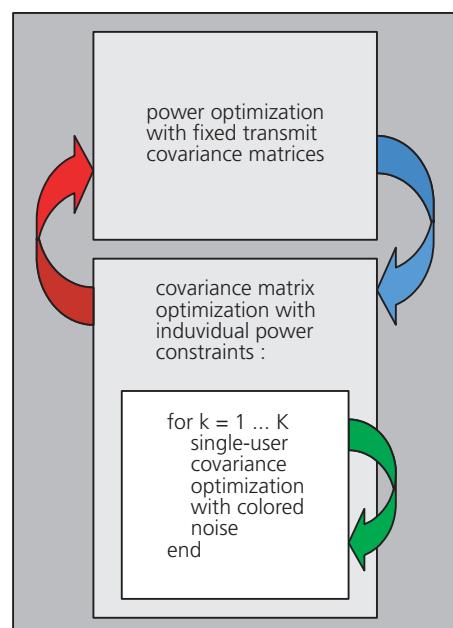


Fig. 2: Sum Performance Optimisation Algorithm

The outer loop is between power allocation and covariance matrix optimisation under individual power constraints. The covariance matrix optimisation can be further decomposed into single-user covariance matrix optimisations. The overall system performance can be significantly improved using the proposed iterative algorithm to compute the transmit strategies.

Reference: E. Jorswieck and H. Boche, Transmission Strategies for the MIMO MAC with MMSE Receiver: Average MSE Optimization and Achievable Individual MSE Region, IEEE Trans. on Signal Processing, vol. 51, no. 11, 2872-2881, Nov. 2003

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CAPACITY OF MIMO SYSTEMS WITH CLOSELY-SPACED ANTENNAS

Data from wide-band radio channel measurements indicate that we may use MIMO techniques also to increase the data rate for small cell phones.

Daten aus einer breitbandigen Messkampagne zeigen, dass man MIMO-Techniken auch zur Erhöhung der Datenrate für kompakte Mobiltelefone einsetzen kann.

From the information-theoretic point of view, radio links with multiple antennas both at the transmitter and at the receiver may have up to N times the capacity of single antenna links, where N is the minimum of the number of transmit and receive antennas. The corresponding multiple-input multiple-output (MIMO) system has recently developed into a major research topic in wireless communications.

One step to bring MIMO techniques into application is to study real-world MIMO channels with realistic antennas. Simple arguments suggest that the MIMO capacity should be reduced when the spacing between the anten-



Fig. 1: Measurement set-up with variable spacing

na elements becomes small (In the extreme case of co-located elements, the received signals are identical and there is no capacity gain at all).

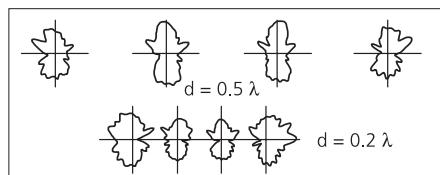


Fig. 2: Measured patterns of individual elements

On the other hand, the coupling between the elements substantially increases when the spacing becomes small. The coupling modifies the beam patterns of the elements, and so it counterbalances the above effect. These effects are studied with a variable element spacing at both sides of the link (see Fig. 1). At first, the individual beam patterns were measured in an an-echoic chamber, with spacings $d = 0.5\lambda$ and 0.2λ where λ is the carrier wavelength (see Fig. 2)

We observe that the individual patterns look almost to the same directions at $d = 0.5\lambda$ but particularly the outer elements look away from the array axis at $d = 0.2\lambda$. In a multipath propagation environment, the elements detect different fractions of the angular spectrum, and so the fading becomes independent although the element spacing is small.

The effect on the MIMO capacities (measured in bps/Hz) is shown in Fig. 3. The data were obtained from measured channel impulse responses. In the indoor data (entrance hall), the MIMO capacity measured at constant SNR is almost independent on the element spacing (top). In the outdoor data (large and almost empty parking lot), the MIMO capacity is at first reduced when the spacing becomes smaller. But just in the region below $d = 0.5\lambda$, where the patterns actually change due to the coupling, a sudden rise is observed, indicating more independent fading between the various antenna elements.

At the same time, the received power is reduced (see center in Fig. 3). This can be explained by the overlap of the effective antenna cross sections reducing the total received signal.

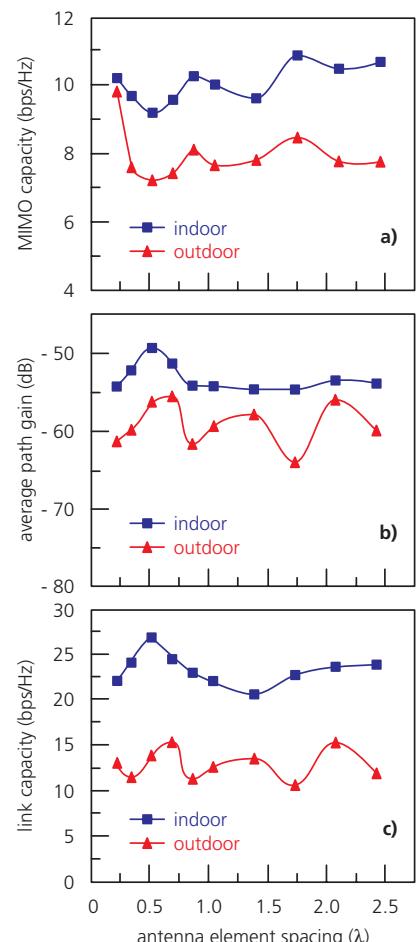


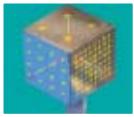
Fig. 3: a) MIMO capacity versus element spacing
b) Average path gain versus element spacing
c) Link capacity versus element spacing

Both effects contribute to the link capacity measured with constant transmit power. At the bottom in Fig. 3 we observe that, altogether, the link capacity is almost independent on the element spacing, both in indoor and outdoor scenarios.

This result shows that MIMO concepts may be used to multiply the data rate for small cell phones as well.

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¹ V. Jungnickel, V. Pohl, C. von Helmolt, IEEE Communications Letters, Vol. 7, No. 8, 2003, pp. 361-363.



REAL-TIME MIMO TRANSMISSION EXPERIMENTS WITH PER-ANTENNA RATE CONTROL (PARC)

A real-time transmission experiment at FhG-HHI has shown that the high spectral efficiency of Multi-antenna systems can be exploited by introducing an adaptive "per Antenna Rate Control" (PARC).

In einem Echtzeitübertragungs-experiment wurde gezeigt, dass die hohe spektrale Effizienz von Multi-Antennen-Systemen ausgenutzt werden kann durch ein adaptives Ratenverteilkonzept pro Sendeantenne (PARC).

Information theory predicts increased capacity when multiple antennas are used at both sides of a radio transmission link. For multiple-input multiple-output (MIMO) systems the capacity scales linearly with the number of antennas by the factor $\min(N, M)$ where N, M are the number of transmit and receive antennas.

Channel measurements indicate that this improvement can be found in indoor environments up to large numbers of antennas.¹ Therefore, MIMO techniques can enhance the performance and capacity of wireless local area networks (WLAN) significantly. In this way, data rates may reach the Gbit/s range, without increasing the spectrum and power requirements.

On the other hand, advanced real-time capable signal processing techniques must be developed to achieve that high throughput.

Our hardware approach (Fig. 2) is based on a hybrid architecture of FPGAs and a DSP for the signal processing. All time critical matrix-vector multiplications are done in the FPGA while the DSP calculates all variable parameters like weight matrices, rate and power allocation vectors. A very

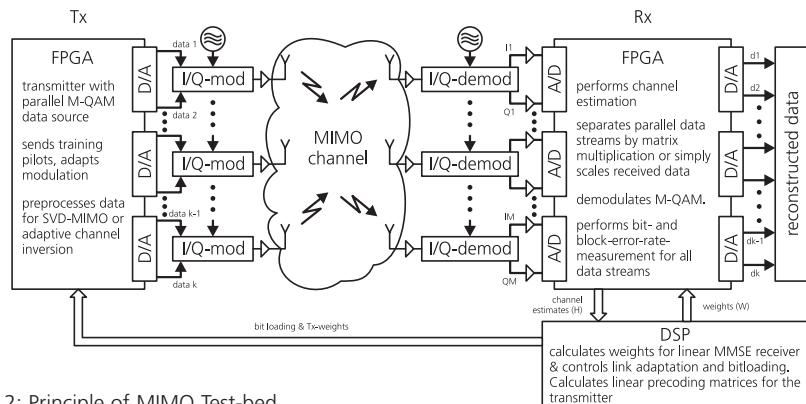


Fig. 2: Principle of MIMO Test-bed

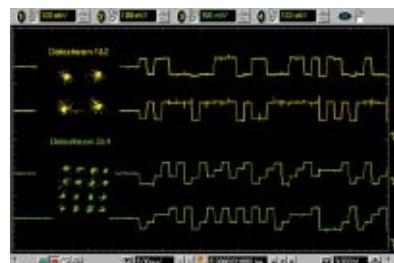


Fig. 1: Reconstructed data streams at the Rx, left: constellation diagrams for QPSK and 16-QAM

important issue that comes into place when spatial multiplexing is done is the possibility to increase the average data throughput or decrease the average bit error rate (BER) if a channel aware rate adaptation is performed.^{2,3} This is very beneficial especially when the degrees of freedom of the system are decreasing due to deep fading of the radio channel. Then e.g. one data stream is switched off and the remaining data streams can profit due to the receive diversity which is then increased by 1. In this way overloaded data transmission on bad channels is avoided. This simple scheme already lowers the outage probability for a fixed BER target.

In the next step a channel aware bit-loading or per antenna rate control (PARC) was implemented (see Fig. 1). Here the SINR in front of the decision unit is calculated by the DSP and the modulation is chosen according to certain BER requirements which are found in look-up tables. This ensures that each antenna transmits the highest possible M-QAM symbol which will satisfy the BER target at the Rx. Applying this technique deep

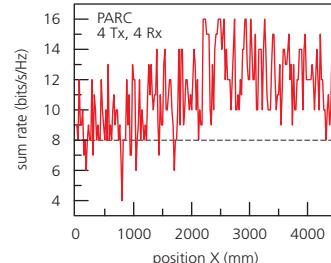


Fig. 3: Spectral Efficiency [bit/s/Hz] versus the position in the room

fading does not produce error bursts any more since the modulation level is lowered step by step or antennas are switched off. Averaged over a sufficient fading statistics which was realized in our lab by driving the Tx antenna 5 m across the room we showed in Fig. 3 that a substantial average rate gain of 38% could be achieved for a MIMO system with 4 Tx and 4 Rx antennas compared with parallel QPSK transmission. The average uncoded BERs were 5×10^{-3} . The allover achieved average payload throughput was 55 Mbit/s with an average spectral efficiency of 11 bit/s/Hz.

The real-time transmission experiments were presented at the Globecom conference in December 2003.

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² V. Jungnickel, T. Haustein, V. Pohl, and C. v. Helmolt, "Link Adaption in Multi-Antenna Systems", IEEE VTC-Spring 2003, Jeju, Korea.

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WIRELESS COMMUNICATIONS AT 60 GHz

Architectures and components are investigated to be applied in a cost effective mobile radio system which allows data transfer with gigabit speed in the 60 GHz-frequency range.

Es werden Architekturen und Komponenten für kostengünstige Mobilfunk-Systeme im 60GHz-Frequenzbereich untersucht, die die Übertragung von Gigabit-Signalen gestatten.

Currently more and more commercial and consumer equipment e.g. personal computers contain high speed interfaces allowing transfer rates up to 1 Gbit/s. It is highly desirable to provide a wireless data connection for high speed internet access. Development of cost effective millimetre-wave components plays a crucial role in order to reach this goal. The FhG-HHI collected many experiences in the past with high speed data communication in the millimetre-wave range. It is well equipped with specific measurement gears and has qualified manpower. For these reasons we can provide support on characterisation of devices and systems for industrial partners.

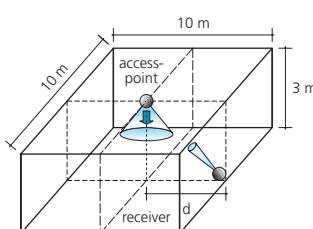


Fig. 1: Wireless indoor transmission link

From the physical point of view different millimetre-wave ranges are suitable for Gbit/s data transmission, but the actual license situation in Germany and all over Europe has to be considered. There are several band segments allocated to civil mobile communication, but bandwidth here does not exceed 200 MHz and data exchange at 1.25 Gbit/s is not possible without

complex signal processing. In the 60 GHz-frequency range higher bandwidth is available. This band has other interesting properties which makes it well suitable and interesting for use in pico-cellular radio systems: There is a high free space attenuation of propagation in this range and a high suppression of the generated signals beyond the walls of a room which is important in security sensitive applications. Looking at the global situation of frequency allocations, it could be noted that there is a license free range in USA and Japan. Due to this fact the industry in these countries has been encouraged to put much effort in research and development of products which are used in commercial available high rated communication links. It makes sense to follow this obvious trend also in Germany. Another attractive topic is the fact that connections may be realized by a small amount of radiated power of some milliwatts. Additionally the size of the needed antennas is small and may not disturb room architecture.

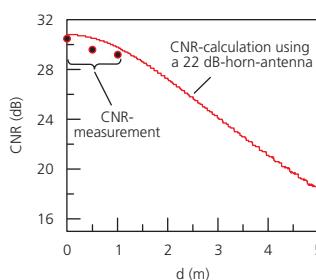
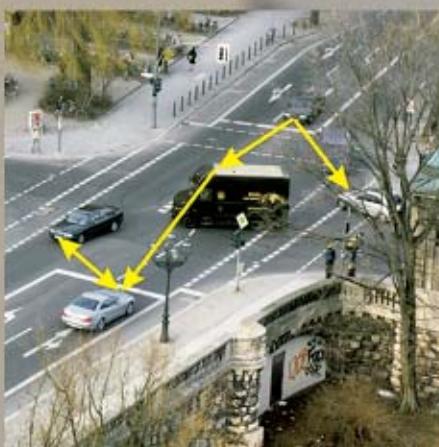
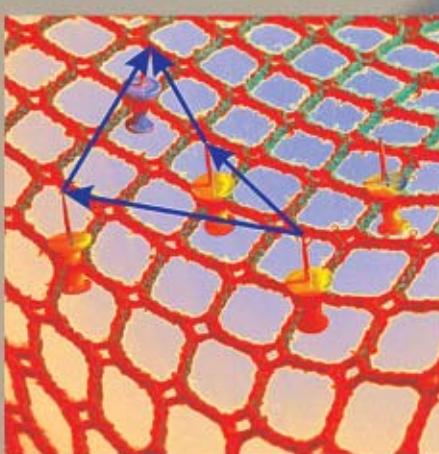


Fig. 2: Wireless indoor 1.25 Gbit/s DBPSK transmission link at 60 GHz, calculated and measured carrier-to-noise ratios (CNR)

The goal of our experiments is to connect PCs equipped with Gigabit-Ethernet cards via a 60 GHz short range radio link. For this application in an indoor environment we think of an architecture as follows (Fig.1): The antenna of the access-point is mounted at the ceiling of a room and shows an omni directional radiation characteristic. The mobile terminal is equipped with a beam antenna and has to be directed to the access point by the user. This beam antenna performs two different functions: At first

the received signal strength on the mobile terminal and the access point is increased. On the other hand fading effects due to reflections and multi-path propagation are minimized. For these investigations a measurement set-up comprising commercially available components has been realized. In the transmitting section a millimetre-wave carrier (56.25 GHz) is modulated by a subcarrier at 3.75 GHz which carries the 1.25 Gb/s data signal in DBPSK-format. The upper modulation sideband with a centre frequency of 60 GHz is radiated by the antenna. In the receiving section we use an antenna with an aperture of about 13 degrees and down convert the received signal to an IF-frequency of 3.75 GHz. The baseband signal is achieved after passing a DBPSK (differential binary phase shift keying) demodulator. The theoretical description of this system is based on the power budget equation for a radio link. With respect to effects of multi-path propagation the Ray-Tracing-method is used. Fig. 2 shows measured and calculated signal to noise ratios at different distances between transmitter and receiver. The quality of the radio link may be evaluated by bit error rate measurements. Nearly error free operation ($BER < 10^{-9}$) is demonstrated at locations where a line of sight connection exists and reflections by walls and other obstacles are suppressed by use of a highly directive antenna. With increasing complexity of the environment with many reflecting obstacles the antenna's directivity has to increase in order to maintain the system performance. As a result a more complex steering system for antenna alignment is required. Alternatively multi-carrier modulation schemes like OFDM or multiple antenna arrangements like MIMO may be used which could reduce multipath propagation effects. The project is part of the joint project "MaiNet". It is funded by the German research ministry BMBF under contract 01BP269. grosskopf@hhi.fhg.de





Fraunhofer German-Sino Lab for Mobile Communications (MCI)

Wireless communication technology has become an important economic factor. Having various applications in different engineering disciplines, the wireless technology plays an important role in research and economy. Large growth rates are anticipated worldwide especially for the pacific area, in particular in China.

The Fraunhofer German-Sino Lab for Mobile Communications (MCI) has been founded to participate in this market. In cooperation with our Chinese partner institute located in Beijing, cutting edge research will be carried out on next generation's cellular networks as well as on wireless networks without infrastructure (co called ad-hoc networks). Possible applications involve telematics, medicine, and control technology.

There is still much room for new innovative applications for mobile communications. More complex networks will be required for mobile internet, multimedia, and multiuser services. These networks will be characterised by coexisting data and speech services. Also, each user will have an individual Quality-of-Service (QoS) requirement. As opposed to classical networks where the link quality is guaranteed by a fixed resource allocation, which is dimensioned for both good and bad channel conditions, future networks will use intelligent scheduling algorithms to optimally exploit the scarce system resources power and bandwidth. Thereby, each user gets a customised share of the overall resource. This strategy makes efficient use of the radio channel and facilitates coexisting services.

Thus, an important field of research is the adaptive, efficient channel allocation in combination with highly efficient multi-carrier and multi-antenna techniques. The MCI develops

- key technologies and systems theory for multi-carrier / multi-antenna techniques
- transmission-efficient algorithmic solutions based on a "vertical" approach which considers multiple relevant communication layers

The goal is the improvement of the spectral efficiency and of the system throughput, as well as the reduction of transmitter power and infrastructure. The following points are especially important from an operator's point of view:

- decrease the cost per bit, thereby facilitate the introduction of new services
- provide the technical support for new services and business models
- decrease the electromagnetic exposure by reducing the transmit power



In this context, the integration and optimisation of new radio access systems plays an important role. So-called multihop structures are able to increase flexibility and coverage of networks. This in turn reduces the cost of the infrastructure.

A further innovative aspect of research are ad-hoc and sensor networks. There are many possible applications. The impact of this new technology has yet to be understood to its full extend. Some examples are logistics, telematics, human factors, surveillance, environmental technology, or smart home applications. Also car-to-car communication is a promising and active area of research. Ad-hoc- and sensor networks are characterised by a simple and efficient implementation. They are also easy to reconfigure, without the need of costly infrastructure. As opposed to other mobile networks, sensor networks are not optimised with respect to throughput but with respect to power efficiency.

The research projects carried out by MCI are funded by industry and the ministry of science and education (Bundesministerium für Bildung und Forschung BMBF).

Fraunhofer German-Sino Lab for Mobile Communications (MCI)

Die Technologie der drahtlosen Kommunikation hat sich zu einem wichtigen ökonomischen Faktor entwickelt. Mit zahllosen Anwendungen in vielen Ingenieursdisziplinen ist sie ein Schwerpunkt in Forschung und Wirtschaft. Weltweit sowie vor allem für den gesamten asiatischen Raum, insbesondere für China, sind weiterhin starke Wachstumsraten zu erwarten.

Die offizielle Gründung des Fraunhofer German-Sino Lab for Mobile Communications (MCI) trägt diesem Umstand Rechnung. In Zusammenarbeit mit dem in Peking ansässigen Partnerinstitut werden zentrale Forschungsthemen auf dem Gebiet der zellularen Mobilfunknetze der nächsten Generation sowie auf dem Gebiet der drahtlosen Netze ohne Infrastruktur (sogenannte Ad hoc Netze) für Anwendungen in der Telematik, Medizin und Steuerungstechnik untersucht.

Insbesondere der Mobilfunk bietet Raum für innovative Anwendungen. Mobiles Internet, Multimediaanwendungen und Mehrbenutzerdienste führen zu komplexeren Netzen. Für diese Netze wird kennzeichnend sein, dass Sprach- und Datendienste nebeneinander existieren und die Nutzer individuelle Anforderungen an die Übertragungsgüte (Quality-of-Service QoS) stellen. Im Unterschied zu klassischen Netzen, in denen die Übertragungsgüte durch feste, überdimensionierte Zuteilung von Übertragungsressourcen garantiert wird, müssen aufgrund der begrenzten Band-

breite komplexe Vergabealgorithmen die Dienstgüte in drahtlosen Netzen sicherstellen. Dabei bekommt der Benutzer einen auf seine Bedürfnisse zugeschnittenen Anteil der zur Verfügung stehenden Ressourcen. Dies ermöglicht einen effektiven Betrieb unterschiedlicher Dienste bei gleichzeitiger optimaler Ausnutzung des Kanals.

Ein wichtiges Forschungsthema ist daher die adaptive, effiziente Vergabe des Funkkanals in Verbindung mit hocheffizienten Mehrträger- und Mehrantennenübertragungsverfahren. Das MCI entwickelt

- Schlüsseltechniken und Systemtheorie für Mehrträger- und Mehrantennenübertragungsverfahren,
- effiziente Algorithmen basierend auf einem vertikalen Ansatz, bei dem eine Optimierung gleichzeitig auf mehreren Kommunikationsschichten durchgeführt wird.

Ziel der Untersuchungen ist dabei die Erhöhung der spektralen Effizienz und des Systemdurchsatzes sowie die Reduktion von Sendeleistung und benötigter Infrastruktur. Für den Mobilfunkbetreiber sind dabei folgende Punkte besonders interessant:

- Die Kosten pro übertragenem Bit sinken. Dies ermöglicht die Einführung neuer Dienste.
- Neue Dienste und Geschäftsmodelle werden technologisch unterstützt.
- Eine reduzierte Sendeleistung verringert die elektromagnetische Exposition.

In diesem Zusammenhang ist auch die Integration und Optimierung neuer Funkzugangssysteme von Bedeutung. Durch sogenannte Multihop-Strukturen können Flexibilität und Abdeckung der Netze erhöht und Infrastrukturstarken gesenkt werden.

Ein weiterer innovativer Aspekt der Forschung sind sogenannte Ad hoc- und Sensornetze. Die Zahl der möglichen Anwendungsbereiche für diese Netze kann noch nicht vollständig abgeschätzt werden. Anwendungsmöglichkeiten finden sich beispielsweise in den Bereichen Logistik, Telematik, Mensch-Maschine Interaktion, Überwachung, Umwelttechnik oder bei Smart-home-Anwendungen. Ein wichtiges Forschungsfeld ist auch die Car-to-Car Kommunikation.

Ad hoc- und Sensornetzwerke zeichnen sich durch einfache, effiziente Implementierung aus und durch die Eigenschaft, leicht rekonfigurierbar zu sein. Dabei benötigen sie keine zusätzliche Infrastruktur. Im Gegensatz zum Mobilfunk steht bei Sensornetzen nicht die spektrale Effizienz, sondern die Energieeffizienz im Vordergrund.

Das MCI behandelt die Forschungsthemen im Rahmen von Industrie- und BMBF Projekten.



Fraunhofer German-Sino Lab for Mobile Communications

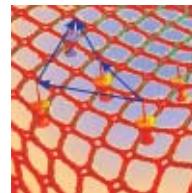
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Mobile systems: Beside voice transmission new services are rising quickly implying needs for network optimisation



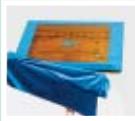
Signboard at the official MCI inauguration



Artist's sketch of a sensor communication network



Ad hoc car to car communication network



SPECTRALLY EFFICIENT MULTIANTENNA SYSTEMS

The Fraunhofer German-Sino Lab for Mobile Communications (MCI) develops a multi-antenna precoding technique, which makes efficient use of the spatial characteristic of the wireless propagation channel.

Das MCI entwickelt eine Mehrantennen-Vorkodierungstechnik, welche die räumliche Ausbreitungseigenschaft des Mobilfunkkanals ausnutzt.

Modern Wireless System use sophisticated signal processing techniques in order to improve the communication link between the base station and the mobile terminal. Today, the theoretical point-to-point link capacity stated by Shannon in 1948 can be closely approached by combined coding, modulation, and equalization techniques. The data throughput is upper-bounded by the system resources power and bandwidth.

Information-theoretical work on multiple-input multiple-output (MIMO) systems carried out in the last decade demonstrate, that a significant gain can be expected by allowing several antennas to cooperate. By antenna cooperation one can exploit the spatial diversity, which is inherent to wireless channels. This insight has led to

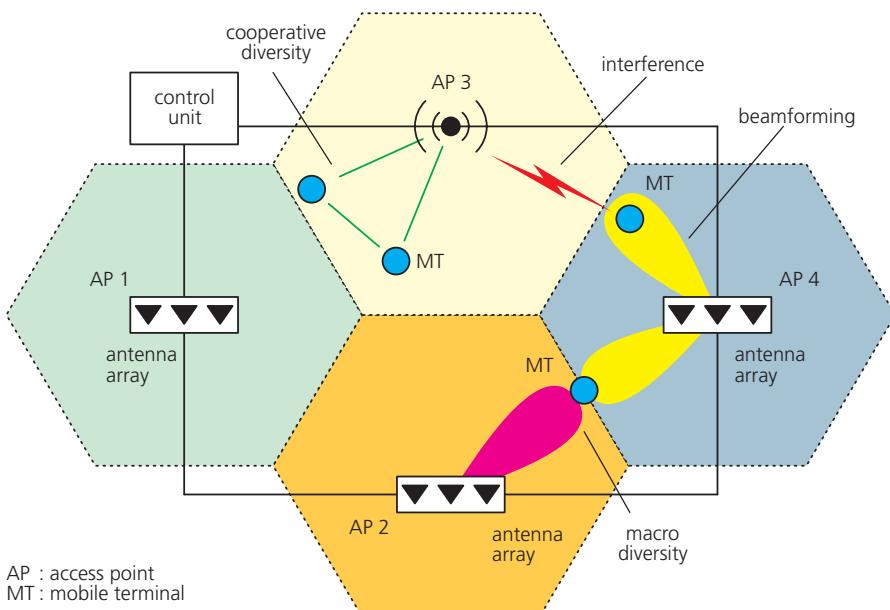


Fig. 2: Seamless Networking with Smart Antennas

very active fields of research, like space-time coding, spatial multiplexing, and cooperative antenna networks. It is anticipated that the conventional hierarchical cell concept will be extended by more flexible and spectrally efficient network structures, which optimally exploit spatial diversity.

The Fraunhofer Sino-German Lab for Mobile Communications (MCI) has developed precoding techniques for transmission of independent data streams over multiple cooperating antennas. Based on knowledge of the propagation channel, precoding can suppress a great deal of the interference (crosstalk) between the users.



Fig. 1: Antenna array in the laboratory

Thereby, the overall system throughput is enhanced and the transmission becomes more reliable. The performance of spatial precoding has been successfully demonstrated on a multi-antenna hardware-testbed.

An interesting application of multi-antenna precoding is its application for distributed antenna networks, where mobile terminals are allowed to cooperate. Such cooperative networks hold a great potential to boost the overall system throughput.

However, such a system-wide approach has to consider many additional aspects, like power control, latency constraints, or traffic patterns. The long-term goal is to develop a seamless network, which extends the hierarchical cell-concept by antenna array transmission (beamforming), MIMO, macrodiversity, and multi-hop networks (see Fig. 2).

The MCI will contribute to this development by designing new algorithms and hardware solutions. The work is supported by the BMBF within the 3GeT project.

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OFDM NEW AIR INTERFACE

A promising concept for UMTS downlink transmission is the incorporation of multicarrier techniques such as orthogonal frequency division multiplexing (OFDM). In addition to W-CDMA air interface the basestation can switch to OFDM downlink air interface for very high data rates in hot spot areas. The development of this air interface is the goal in this project.

Ein interessantes, neues Konzept für die UMTS Abwärtsstrecke stellt die orthogonal frequency division multiplexing (OFDM) Mehrträgerübertragung dar. Hierbei ist vorgesehen, dass zusätzlich zur W-CDMA Abwärtsstrecke je nach Szenario eine OFDM Luftschnittstelle für sehr hohe Datenraten hinzugeschaltet wird. Die Entwicklung dieser Luftschnittstelle ist das Ziel in diesem Projekt.

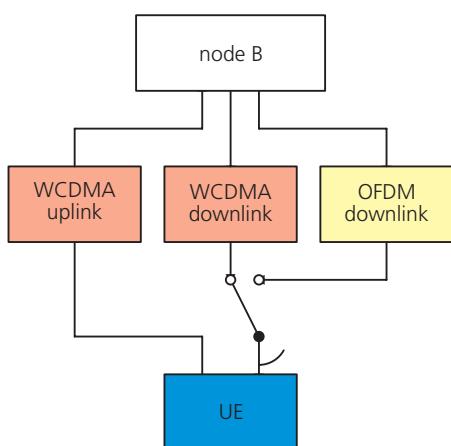


Fig. 1: UMTS New Air Interface using OFDM

The evolution of UMTS (universal mobile telecommunications system) towards higher bit rates is in rapid progress with the development of HSDPA (high speed downlink package access) based on W-CDMA (wideband code division multiple access). Introduced in the 3rd generation partnership project (3GPP) release 5 standard, HSDPA aims at peak data rates of approximately 10 [Mbit/s] in order

to support packet-based multimedia services. Release 6 will include antenna array and MIMO (multiple input multiple output) techniques and is expected to achieve peak data rates of 20–30 [Mbit/s].

Beyond this development further enhancement is discussed with the inclusion of new air interfaces and multi-standard environment. A promising concept for the downlink is the incorporation of an orthogonal frequency division multiplexing (OFDM) modem. OFDM attracted much attention in the past due to implementation-efficient FFT signal processing. The definition of a new air interface using OFDM in combination with HSDPA for UMTS downlink transmission is a challenging task and focus of this research.

The multicarrier technique OFDM can be traced back to the early seventies where Weinstein and Ebert proposed practical fast Fourier transform (FFT) techniques to generate the transmit signal and thereby overcoming the crucial synchronization issue. Since then, OFDM has become a popular communication technique and has been indeed chosen for several communication standards such as x-DSL, IEEE 801.11a and DVB.

The basic idea of multicarrier transmission is to partition the channel into approximate so-called eigenfunctions that pass the channel without much distortion. In OFDM the transmit signal is composed of a number of orthogonal harmonic subcarriers. It can be shown that these are well-suited to the time-invariant channel and even optimal in time-invariant multipath channel. A typical simulation chain includes FFT modulation and demodulation, channel estimation and synchronization. New efficient algorithms will be developed for these entities that are tailored to the problem. Furthermore, a particular well known problem is the high dynamics

of the transmit signal. Thus, of particular interest will be the development of measures to cope with nonlinear components such as the power amplifier based on recent fundamental results.^{1,2} It is to emphasize that also new developments such as IOTA Offset-QAM modulation and iterative pulse shape optimization will be incorporated into the design.

A further main focus is on the OFDM broadcast channel due to the multi-user downlink scenario. OFDM can be regarded as a multiuser scheme if more users exclusively share the available number of subcarriers. Even though the combination of OFDM and FDMA may not always be the optimal scheme it is used since receiver complexity will be low. On the other hand, the so-called resource scheduling, i.e. power allocation and bitloading problem in combination with the subcarrier allocation problem becomes a complex problem. Basically, any practical scheduling scheme involves the optimization of a physical performance measure such as sum capacity in combination with a QoS measure such as delay constraints and rate requirements under the channel condition. For the considered downlink problem new scheduling solutions will be devised supporting individual user constraints as well as maximizes the total system throughput.

This research is supported by the German Ministry of Research and Education under grant 01BU350 and by industries.

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CROSS-LAYER OPTIMIZATION OF WIRELESS AD HOC NETWORKS

A wireless ad hoc network is a collection of communication devices that self-organize to form a network without the aid of pre-established infrastructure. Such networks have an enormous potential for consumer applications, but also present several fundamental technical challenges.

Ein drahtloses Ad hoc Netz ist eine Sammlung von Kommunikationsgeräten, die sich ohne die Hilfe einer festen Infrastruktur vernetzen können. Derartige Netze bieten enorme Möglichkeiten für viele Anwendungen. Allerdings ist ihre Realisierung mit großen technischen Herausforderungen verbunden.

Driven by the steady outcome of new applications, wireless ad hoc networks will rapidly grow in importance in near future. Such networks can be easily deployed, reconfigured and tailored to specific applications, thereby reducing the implementation costs significantly. In addition to numerous applications in logistics, surveillance, monitoring, home and business environment (agent systems, man-machine interaction, smart home and office integration), wireless ad hoc networks will play a key role in automotive and traffic telematics. Different applications pose their own particular requirements on the communication system in terms of delay, communication range, reliability, positioning accuracy, and bandwidth. In particular, in wireless sensor networks rather than spectral efficiency, energy efficiency, i.e. the effective energy consumption per transmitted bit, is the major concern.

The Fraunhofer German-Sino Lab for Mobile Communications set up projects that deal with the network design problems. At present we focus

on two of the most promising applications for wireless ad hoc networks.

Inter-Vehicle Communications

Several recent research results indicate that ad hoc mechanisms such as multihop routing can significantly increase spectral efficiency, reliability and flexibility of inter-vehicle communications systems. However, achieving these gains with ideal multihop routing strategies remains elusive. In particular, the high channel and network dynamics coupled with multihop routing make it difficult to support high speed and low delay requirements of many important applications. This presents some fundamental technical challenges for reliable inter-vehicle communications.

Our research activities focus on developing communication algorithms that guarantee high spectral efficiency, reliability and flexibility, on the one hand, and the quality-of-service requirements for applications, on the other hand. The best system performance should be achieved by jointly optimising the three lowest layers of the protocol stack, namely the physical layer, the link layer and the network layer. This includes the development of adaptive strategies that adjust mobile node parameters such as transmission power, coding and modulation to a time-varying radio propagation channel. Moreover, to increase spectral efficiency, the use of multi-antenna techniques is investigated. On the link layer, dynamic power control and smart link scheduling are necessary to guarantee the continuous data flow. All these should be combined with robust multihop routing protocols for low-delay high-speed applications.

Wireless Sensor Networks

The possibility that large numbers of low-cost, power efficient sensing devices can be deployed without fixed infrastructure for a range of monitoring and data gathering applications has opened up a wide array of

research areas. In addition to relatively low computing power, the energy consumption is the main design and operational constraint of wireless sensor networks. Severe energy constraints and limited computing resources impact all layers of protocol designs.

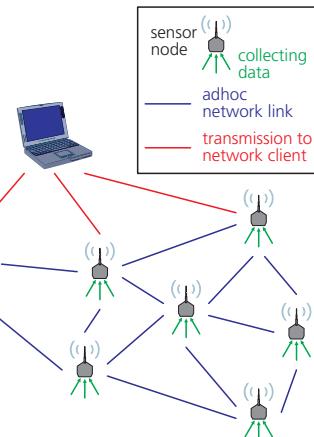


Fig. 1: A wireless sensor network: A large number of low-cost power-efficient sensing devices deployed without fixed infrastructure for a range of monitoring and data-gathering applications

Consequently, instead of the traditional approach of maximising the spectral efficiency, the main focus here is on minimising the energy consumption per transmitted bit for given bandwidth and data rate. This requires the development of new energy efficient transmission techniques in the wideband regime. Furthermore, in many sensor networks, distributed coding for correlated sources is essential for enhancing the system performance. When developing such coding algorithms, it is necessary to minimise the communication between nodes. Appropriate distributed signal processing should provide a solution to this problem. Finally, we aim at developing energy efficient multihop routing strategies for different applications and network topologies. To guarantee the best performance, an adaptive energy efficient cross-layer design is necessary that supports adaptivity and optimisation across all protocol layers.

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FOOTNOTES

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- M. Möhrle, BH-Laser mit getapertem optischen Wellenleiter, insbesondere BH-DFB-Laser (BH-DFB-laser with tapered optical waveguide), DE 103 30 019.8
- D. Marpe, H. Schwarz, Th. Wiegand, Apparatus and methods for entropy-encoding or entropy-decoding using an initialisation of context variables, US 10/623,096
- D. Marpe, H. Schwarz, Th. Wiegand, Method and apparatus for binarization and arithmetic coding of a data value, US 10/622,335
- Ch. Windpassinger, R. Fischer, Nichtlineares Vorcodierungsverfahren für einen digitalen Broadcastkanal (Nonlinear precoding method for a digital broadcast channel), DE 103 33 514.5
- B. Duckstein, S. Pastoor, D. Przewozny, H. Röder, K. Schenke, Verfahren zur Anzeigesteuerung von unterschiedlichen Informationen in einem Fahrzeug und opto-acustische Informationseinheit (Method for control of display of different information contents in a vehicle and opto-acoustic information unit), DE 103 39 314.5
- D. Marpe, H. Schwarz, Th. Wiegand, Vorrichtung und Verfahren zum Codieren einer Gruppe von aufeinanderfolgenden Bildern und Vorrichtung und Verfahren zum Decodieren eines codierten Bildsignals (Method and arrangement for encoding of a group of consecutive pictures and method and arrangement for decoding a coded video signal), DE 103 40 407.4
- C. Bornholdt, B. Sartorius, J. Slovak, Wellenlängen-erhaltender optischer Signalregenerator (Wavelength preserving optical signal regenerator), DE 103 44 319.3
- J. Berger, Ch. Börner, Optischer Multi-Kanal Demultiplexer auf der Basis eines einzelnen optischen Schalters (Optical multi-channel demultiplexer based on a single optical switch), DE 103 44 314.2
- Th. Dekorsy, N. Georgiev, M. Helm, H. Küntzel, Quantenkaskadenlaser (Short wavelength quantum cascade laser), DE 103 55 949.3
- D. Marpe, H. Schwarz, Th. Wiegand, Video frame or picture encoding and decoding, US 10/728,426
- D. Marpe, H. Schwarz, Th. Wiegand, Coding of a syntax element contained in a pre-coded video signal, US 10/667,886

AWARDS

S. Bischoff, **Best paper award** from the KI2003 program committee (26th German Conf. on Artificial Intelligence) for the paper "Applied connectionistic methods in computer vision to compare segmented images", (together with D. Reuss and F. Wysotski from TUB).

H. Boche, **Alcatel SEL Foundation Award** "Technical Communication".

S. Bauer, O. Brox, **Best Patent Award** of the Association of the Friends of the HHI for the patent "Optische Mikrowellenquelle (Optical microwave source)" applied in 2001, Berlin, Nov. 2003.

ACCEPTANCE OF CHAIRS

Michael Rohde took up a professorship in the area of Data Communication and Optical Telecommunication at the University of Applied Sciences in Berlin.

Ulrike Busolt took up a professorship in the area of Medical Engineering at the University of Applied Sciences in Furtwangen, Campus Schwenningen, Department Mechanical Engineering.

DOCTORATE THESES

E. Hilliger, **Optical switching with electro-absorption**, TU Berlin, Fakultät II – Mathematik und Naturwissenschaften, Prof. Dr. H. J. Eichler (TUB), Prof. Dr. H.-G. Weber.

M. Rohde, **Prüfmodulationsverfahren zur Überwachung von transparenten WDM-Netzen (Control modulation techniques for monitoring of transparent WDM networks)**, TU-Berlin, Fakultät IV – Elektrotechnik und Informatik, Prof. Dr.-Ing. Petermann (TUB).

S. Stanczak, **Resource allocation, sequence design and channel estimation for code-division-multiple-access channels**, TU Berlin, Fakultät IV - Elektrotechnik und Informatik, Prof. Dr. Dr. H. Boche, Prof. Dr. J. Hagenauer (TU München).

G. Wunder, **A theoretical framework for the peak-to-average power control problem in OFDM transmission**, TU Berlin, Fakultät IV - Elektrotechnik und Informatik, Prof. Dr. Dr. H. Boche.

DIPLOMA THESES

S. Adolf, **Analyse und Implementierung von zeitlichen Prädiktionsverfahren in einem hybriden Videocodec (Analysis and implementation of methods for temporal prediction in a hybrid videocodec)**, Technische Fachhochschule Berlin (TFH), FB Mathematik. Supervisor at HHI: D. Marpe.

M. Dröse, **Entwicklung von Verfahren zur Segmentierung, Verfolgung und 3D-Rekonstruktion von bewegten Objekten in Verkehrsszenen mit mehreren Ansichten (Development of algorithms for segmentation, tracking and 3D reconstruction of moving objects in traffic scenes using multiple cameras)**, TU Berlin, Fakultät IV – Elektrotechnik und Informatik. Supervisor at HHI: A. Smolic.

H. Gäbler, **Entwicklung eines adaptiven QAM/PSK Modulators und Demodulators sowie Implementierung im FPGA (Development of an adaptive QAM/PSK modulator and demodulator as well as the implementation in a FPGA9)**; Technische Fachhochschule Berlin (TFH), FB Elektrotechnik. Supervisor at HHI: V. Jungnickel.

S. Jatta, **Noise modelling of InP-based heterostructures field effect transistors and travelling wave amplifiers**, TU Berlin, Fakultät IV – Elektrotechnik und Informatik. Supervisors at HHI: H.-G. Bach and G.G. Mekonnen

B. Kaspar, **Vergleich und Bewertung verschiedener Verfahren zur 3D Objektrekonstruktion aus Multiview-Kameraaufnahmen (Comparison of algorithms for 3D object reconstruction from multiple views)**, Fachhochschule Köln, FB Photoingenieurwesen und Medientechnik. Supervisor at HHI: A. Smolic.

D. Kaßner, **Implementation and investigation of forward error correcting codes (FEC) in optical wavelength division multiplex (WDM) networks**, Technische Fachhochschule Berlin (TFH). Supervisor at HHI: E.-J. Bachus, M.Rohde.

Y. Kondratyuk, **Hand tracking and segmentation in video sequences for assisted 3D analysis in real-time video conferencing**, TU Berlin, Fakultät IV – Elektrotechnik und Informatik. Supervisor at HHI: O. Schreer.

H. Kretschmer, **Design, synthesis and implementation of a VHDL-model for an IDE-harddisc-controller that complies with ATA-standard**, TU-Berlin, Fakultät IV – Elektrotechnik und Informatik. Supervisors at HHI: M. Talmi, T. Weber.

J.-R. van Look, **Wellenleiterkopplung in integriert-optischen Bauelementen basierend auf Photonischen Kristallen (Investigations to intrachip wavelength coupling on integrated optical devices based on photonic crystals in the material compound InGaAsP / InP)**, TU Berlin, Fakultät II – Mathematik und Naturwissenschaften. Supervisors at HHI: Prof. Dr. B. Kuhlow, H. Heidrich.

L. Molle, **System margins and parameter tolerances at 40Gb/s transmission in metro regions**, TU Berlin, Fakultät IV – Elektrotechnik und Informatik. Supervisor at HHI: E.-J. Bachus.

J. Mühlhause, **Implementation and integration of a motion-compensating filter for noise reduction into a format converter**, TU Berlin, Fakultät IV – Elektrotechnik und Informatik. Supervisor at HHI: M. Hahn.

M. Müller, **Entwicklung eines Disparitäts-schätzers zur Anwendung in Immersive TV Anwendungen (Development of a disparity estimator for use in immersive TV applications)**, TU Berlin, Fakultät IV – Elektrotechnik und Informatik. Supervisor at HHI: C. Fehn.

E. Pertzsch, **Dry-etching technology to realise "intelligent" laser facets**, Fachhochschule für Technik und Wirtschaft (HTW), Berlin. Supervisor at HHI: M. Möhrle.

T. Schierl, **Video streaming over internet using the H.264/AVC video coding standard**, TU Berlin, Fakultät IV – Elektrotechnik und Informatik. Supervisor at HHI: T. Wiegand.

E. W. Suryaputra, **Optimization of the light coupling from edge-emitting LEDs to tapered monomode fibres**, TU Berlin, Fakultät II – Mathematik und Naturwissenschaften. Supervisor at HHI: A. Paraskevopoulos.

Y. Vatis, **Entwicklung und Untersuchung von Verfahren zur Videocodierung unter Verwendung von Superresolutionsmosaiken (Development and evaluation of algorithms for video coding using super-resolution mosaics)**, TU Berlin, Fakultät IV – Elektrotechnik und Informatik. Supervisor at HHI: A. Smolic.

P. Voigt, **Entwicklung und Untersuchung eines Multiclients für die Videoüberwachung mit mehreren Kameras (Development and evaluation of a multi-client system for video surveillance with multiple cameras)**, TU Berlin, Fakultät IV – Elektrotechnik und Informatik. Supervisor at HHI: K. Müller.

S. Voß, **Development of a performance-optimized MPEG-4 AAC encoder for embedded processors**, TU Berlin, Fakultät IV – Elektrotechnik und Informatik. Supervisor at HHI: M. Talmi.

C. Zhou, **Scheduling Strategien für Mehrnutzerdetektion mit Multi-Antennen-System an der Basisstation, (Scheduling Strategies for multi-user detection with multi-antenna system at the base station)**, TU Berlin, Fakultät IV – Elektrotechnik und Informatik. Supervisor at HHI: T. Haustein.

GRADUATE THESES

E. Dönmez, **Development of a flexible video interface board with four video in- and outputs in full TV resolution**, TU Berlin, Fakultät IV – Elektrotechnik und Informatik. Supervisors at HHI: M. Karl, O. Schreer.

K. Elazouzi, **Initialization of hand tracking and segmentation in real-time**, TU Berlin, Fakultät IV – Elektrotechnik und Informatik. Supervisor at HHI: O. Schreer.

R. Elschner, **Analysis of gain saturation of gain clamped SOA as optical switches for optical burst switching nodes**, TU Berlin, Fakultät IV – Elektrotechnik und Informatik. Supervisor at HHI: H. Buchta.

S. Jatta, **Noise characterisation of InP-HEMTs**, TU Berlin, Fakultät IV – Elektrotechnik und Informatik. Supervisors at HHI: H.-G. Bach and G.G. Mekonnen.

S. Voß, **Experimental optimization of elementary parameters related to a psycho-acoustic model**, TU Berlin, Fakultät IV – Elektrotechnik und Informatik. Supervisor at HHI: M. Talmi.

J. Weil, **Implementation of an MPEG-4 CELP Encoder**, TU Berlin, Fakultät IV – Elektrotechnik und Informatik. Supervisor at HHI: M. Talmi.

ORAL PRESENTATIONS

C. Fehn, **A 3D-TV Approach Using Depth-Image Based Rendering (DIBR)**, invited Talk at Workshop on Immersive Communication and Broadcast Systems (ICOB 2003), Berlin, January 2003.

O. Schreer, **VIRTUE – The Real-Time Platform**, invited Talk at Workshop on Immersive Communication and Broadcast Systems (ICOB 03), Berlin, January 2003.

A. Smolic, **MPEG 3DAV – Standardization of 3D Audio and Video**, invited Talk at Workshop on Immersive Communication and Broadcast Systems, Berlin, January 2003.

J. Faber, D. Ruschin, **Can one achieve any look with any image acquisition device?**, Berlinale Talent Campus 2003, Berlin, 12.2.2003.

R. Schäfer, **MPEG-4 und H.264/AVC – Neue Videocodierstandards für die Multimediaübertragung**, FKTG Regionalveranstaltung – MDR, Leipzig, 19.2.2003.

R. Schäfer, **Videocodierung und -streaming für Kommunikation und Überwachung**, ESK-Workshop Inhouse-Kommunikation von Morgen, München, 21.2.2003.

R. Schäfer, **Bildsignalverarbeitung**, IMS-Kolloquium, Stuttgart, 28.2.2003.

K. Schenke, **Display- und Interaktionstechniken für Mixed Reality**, CeBit 2003 Future Talk, Hannover, 15.3.2003.

T. Wiegand, **Videocodierung mit dem H.264/AVC-Standard**, IRT München, March 2003.

D. Marpe, **New developments and standards in video coding** (invited), Workshop Image and Video Coding and its Applications, Berlin, 9.4.2003.

G. Walf, **Evolution of Photonic Networks** (invited), µsys Berlin (DE), 28.–29. April 2003.

I. Feldmann, **Robuster Epipolarbildansatz zur 3D-Szenenanalyse für beliebige Kamerabewegungen** (invited), Technical University, Berlin, April 2003.

K. Müller, **Multimedia descriptors in MPEG-7** (invited), Milestones in Image and Video Coding, Berlin, April 2003.

M. Ferstl, **Diffraktive Optische Elemente** (invited), Carl Zeiss Kolloquium: "Diffraktive Optik", Oberkochen, 8.5.2003.

R. Steingrüber, **Elektronenstrahlolithographie am HHI** (invited), Carl Zeiss Kolloquium: "Diffraktive Optik", Oberkochen, 8.5.2003.

D. Marpe, **Entropy coding in the H.264/AVC video coding standard** (invited), Institute of Electronics and Telecommunications, Poznan University of Technology, (PL), 14.5.2003.

Th. Rosin, **Multifaserkopplung für schräg zur Kristallkante liegende Wellenleiter**, Workshop Photonische Aufbau- und Verbindungsstechnik, Wernigerode, 16.5.2003,

C. Schubert, **Interferometrische Schalter in der optischen Signalverarbeitung**, Seminar des Optischen Instituts, Berlin 16.5.2003.

C. Schmidt-Langhorst, **Optisches Sampling von hochratigen optischen Datensignalen**, Seminar des Optischen Instituts, Berlin, 23.5.2003.

T. Wiegand, **The emerging H.264/AVC video coding standard and beyond**, Cambridge University, Cambridge (UK), May 2003.

T. Wiegand, **The emerging H.264/AVC video coding standard and beyond**, TU Wien (AT), May 2003.

R. Schäfer, **MPEG-4 und H.264/AVC – Neue Videocodierstandards für die Multimediaübertragung**, FKTG-Regionalveranstaltung, Ilmenau, 10.6.2003.

K. Hopf, **Autostereoscopic 3D Display**, Future Talk CeBit america 2003, New York (USA), 18.6.2003.

M. Hahn, **Formatkonversion**, Symposium 'Die Qualität des Fernsehbildes' Media Vision Cologne, Köln, June 2003.

M. Hahn, **High-Definition Übertragung – Utopie oder schon bald Realität?**, Kolloquium 'HD-Event 2003', Media City Leipzig, June 2003.

J. Slovak, **Charakterisierung der optischen Taktrückgewinnung für einen 3R Regenerator bei 40 Gbit/s**, Seminar mit Prof. Petermann – TU Berlin, June 2003.

K.-D. Langer, **Challenges of optical access networks**, (invited), Int. Conference on Transparent Optical Networks (ICTON 2003), Warsaw (PL), 29.6.–3.7.2003.

C. Fehn, **Compression, Transmission and Rendering for the ATTEST 3D-TV System** (invited Talk), Visual Communications and Image Processing (VCIP 2003), Lugano, (CH), July 2003.

O. Schreer, **Advances in Immersive Video Communication**, Invited talk at Univ. of Pennsylvania, Computer and Information Science, Philadelphia (USA), July 2003.

O. Schreer, **Current state of research on Immersive Video Conferencing**, Invited Talk at

- Univ. of North Carolina Chapel Hill, Department of Computer Science, Chapel Hill (USA), July 2003.
- O. Schreer, **Immersive Video Communication**, Tutorial given at International Conference on Multimedia and Expo (ICME), Baltimore, (MD) (USA), July 2003.
- E. Cooke, **Modular Multi-View Synthesis in a Scalable Image-Based Rendering System**, Invited Talk at The Centre for Digital Video Processing, Dublin City University, Dublin (IE), August 2003.
- C. Fehn, **ATTEST – Ein evolutionärer Ansatz für drei-dimensionales Fernsehen (3D-TV)** (invited Talk), Internationalen Funkausstellung 2003, Berlin, August 2003.
- A. Smolic, **Multiview Videostreaming und 3D Szenenrekonstruktion für Interaktive Multimediadienste**, (invited Talk) Internationale Funkausstellung 2003, Berlin, August 2003.
- M. Hahn, **Videoformate und Flachbildschirme für das Fernsehen der Zukunft**, Talk im TWF der IFA 2003, Berlin, 2.9.2003.
- D. Marpe, **Der neue Videocodierstandard H.264/AVC**, Talk im TWF der IFA 2003, Berlin, 2.9.2003.
- S. Renault, **Display- und Interaktionstechniken für Mixed Reality**, Talk im TWF der IFA 2003, Berlin, 2.9.2003.
- G. Walf, **Glasfaseranschluß für Jedermann**, (invited), Handwerkskammer Berlin (DE), 2.9.2003.
- T. Wiegand, G. J. Sullivan (Microsoft), **The H.264/MPEG-4 AVC Video Coding Standard**, Tutorial given at International Conference on Image Processing, Barcelona (ES), 14.9.2003.
- R. Schäfer, **H.264/AVC Video Coding Standard**, ISMA Session – IBC 2003, Amsterdam, 15.9.2003.
- S. Bauer, **Synchronisation processes in lasers: Resonances on tori**, 3. Workshop on Dynamics of Semiconductor Lasers, Berlin, 15.–17.9.2003.
- O. Brox, **External locking properties of 40 GHz self-pulsating lasers**, 3. Workshop on Dynamics of Semiconductor Lasers, Berlin, 15.–17.9.2003.
- H. Künzel, **MBE grown GaInAs/AlAsSb multiple quantum wells lattice matched on InP substrates**, COST 288 meeting, Turin (IT), 17.–18.9.2003.
- R. Schäfer, **Video Coding – Present and Future**, VLBV '03, Madrid (ES), 18.-19.9.2003.
- T. Weber, **Multistandard Audio/Video-Prozessor MAViP**, ITG/FKTG-Fachtagung Elektronische Medien (10. Dortmunder Fernsehseminar), Dortmund, 30.9.2003.
- M. Hahn, **Problems of Video Format Conversion; Solutions with HiCon**, Workshop Harmann International, Villingen-Schwenningen, September 2003.
- O. Schreer, P. Kauff, **Concepts, Systems and Algorithms for Immersive Video Communication**, Tutorial given at 25th Pattern Recognition Symposium (DAGM 2003), Magdeburg, September 2003.
- E. Schulze, **Signalspitzen in geschalteten Raman- und EDFA-verstärkten WDM-Systemen**, DFG-Abschluss-Kolloquium, Optische Übermittlungsverfahren in der Informationstechnik, Berlin, 6.–7.10.2003.
- C. Börner, **Optisches Sampling von hoch-ratigen optischen Daten-Signalen**, DFG-Abschluss-Kolloquium Optische Übermittlungsverfahren in der Informationstechnik, Berlin, 6.–7.10.2003.
- E. Hilliger, **Ultraschneller optischer Schalter auf der Basis sättigbarer Absorber und Halbleiterlaserverstärker**, DFG-Abschluss-Kolloquium Optische Übermittlungsverfahren in der Informationstechnik, Berlin, 6.–7.10.2003.
- V. Marembert, **Optisches Schalten auf der Basis von Halbleiter-Laserverstärkern mit nichtperiodischen optischen Signalen**, DFG-Abschluss-Kolloquium Optische Übermittlungsverfahren in der Informationstechnik, Berlin, 6.–7.10.2003.
- D. Marpe, **Der neue Videocodierstandard H.264/AVC** (invited Talk), Symposium Codierung audiovisueller Daten, 3. Wiesbadener Medienkolloquium, Wiesbaden (DE), 29.–30.10.2003.
- R. Schäfer, **Digital Extended Broadcasting – DXB**, 3. Wiesbadener Medienkolloquium, Wiesbaden (DE), 29.–30.10.2003.
- R. Schäfer, **Videocodierung für Fernsehen, Bildkommunikation und Multimedia**, 3. Wiesbadener Medienkolloquium, Wiesbaden (DE), 29.–30.10.2003.
- A. Smolic, **Video-Based Rendering und 3D Rekonstruktion für Interaktive Medien**, (invited Talk) 3. Wiesbadener Medienkolloquium, Wiesbaden (DE), 29.–30.10.2003.
- H. Buchta, **Viability and Performance of Optical Burst Switching – Technology and Realization**, Workshop TransiNet2003, München (DE), October 2003.
- S. Renault, **Display- und Interaktionstechniken für Mixed Reality Kiosksysteme**, EVA Conference International, 12.11.2003.
- K. Habel, **Systemdesign optischer Übertragungsstrecken mit Hilfe statistischer Methoden**, Workshop der ITG Fachgruppe 5.3.1 Modellierung photonischer Komponenten und Systeme, Backnang (DE), November 2003.
- N. Grote, **Planares selektives MOVPE-Wachstum von InP mittels TBCI-Unterstützung**, 18. DGKK-Workshop in Bremen "Epitaxie von III-V-Halbleitern", 11.–12.12.2003.
- T. Meiers, **MPEG-7 basierte Bild- und Videoarchivierung**, Expertenworkshop "MPEG-7 Verfahren und Anwendungen", FhG Institut für Medienkommunikation, St. Augustin (DE), 17.12.2003.
- K. Müller, **Beschreibung von Multimedialhalten durch MPEG-7**, (invited Talk) FKTG Regionalveranstaltung Stuttgart, December 2003.

LECTURES

- H.-G. Bach, Grundlagen der optoelektronischen Halbleiterbauelemente, TU Berlin
- H.-G. Bach, Messverfahren für Halbleiterbauelemente, TU Berlin
- E.-J. Bachus, Photonische Kommunikationsnetze, TU Berlin
- H. Boche, Digitale Mobilkommunikation I+II, TU Berlin
- H. Boche, Space-Time Signalprocessing für die Mobilkommunikation, TU Berlin
- H. Boche, Mehrnutzer-Informationstheorie, TU Berlin
- H. Boche, Paraktikum-Space-Time-Signalprocessing, TU Berlin
- P. Eisert, Visualisierung, Codierung und Übertragung virtueller 3D Welten, TU Berlin
- L. Ihlenburg, Entwicklungstendenzen der Multimediacommunikation, TU Berlin
- V. Jungnickel, MIMO Übertragungssysteme, TU Berlin
- V. Jungnickel, Adaptive Übertragungsverfahren im Mobilfunk I+II, TU Berlin
- V. Jungnickel, Mehrnutzerinformationstheorie, TU Berlin
- I. Keller, Klassifikation in der Nachrichtentechnik, TU Berlin
- A. Kortke, Praktikum Digitale Mobilkommunikation I+II, TU Berlin

- B. Kuhlow, Einführung in die Photonik, TU Berlin
- B. Kuhlow, Einführung in die optische Signalverarbeitung, TU Berlin
- B. Kuhlow, Photonik, TU Berlin
- O. Schreer, 3D Bildsynthese in der Videokommunikation, TU Berlin
- O. Schreer, Stereobildverarbeitung in der Videokommunikation, TU Berlin
- M. Schubert, Raum-Zeit Signalverarbeitung, TU Berlin
- A. Smolic, Entwicklungstendenzen der Multimediacommunikation, TU Berlin
- P. Stammnitz, Einführung in Kanalcodierungsverfahren, TU Berlin
- S. Stanczak, Mehrnutzerdetektion für drahtlose Kommunikationssysteme, TU Berlin
- H. G. Weber, Grundlagen und Anwendungen der linearen und nichtlinearen Faseroptik, TU Berlin
- T. Wiegand, Digital Image Communication, TU Berlin
- G. Wunder, Statische Signalverarbeitung Detection and Estimation, TU Berlin

WORKSHOPS ORGANISED

- Workshop on Immersive Communication and Broadcast Systems (ICOB 2003), HHI Berlin, January
- ITG/FKTG-Workshop Multimedia Technologien für zukünftige Heim-Displays, HHI Berlin, March
- Aspekte zur Bildqualität von High Definition, HD-Event 2003, Leipzig, June
- Statusseminar MultiTeraNet, HHI Berlin, June
- Special Session on Immersive 3D Video Communication, International Conference on Visual Communication and Image Processing (VCIP 2003), Lugano (CH), July
- European Leica Beamwriter Users Meeting (ELBUM), Cambridge, UK, September
- MaiNet Workshop Breitbandiger Teilnehmeranschluss, HHI Berlin, September
- Workshop Perspektiven der terrestrischen Datendienste über DVB-T, DVB-H und DAB, HHI Berlin, November
- 19th International Symposium on Human Factors in Telecommunication (HFT 03), HHI Berlin, December

CONTRIBUTIONS TO EXHIBITIONS

- ICOB 2003**, Berlin, January:
Facial animation for low bit-rate communication
- CeBIT 2003**, Hanover (DE), March:
3D Displays for interactive media (Hand-, Head, and Gaze tracker)
MPEG-7 based image retrieval
Sensing People – Intelligent cameras and sensors
IM3DVC – Immersive 3D video conference
CineBox – Immersive projection for D-Cinema
H.264/AVC video streaming
MPEG-4 facial animation
- Picture Coding Symposium**, St. Malo (FR), April:
Metadata for advanced scalable video coding tools (MASCOT), final demonstration of IST project MASCOT
- Lange Nacht der Wissenschaften**, Berlin, June:
The Internet of tomorrow
Interaction with virtual objects
Multiview traffic analysis and 3D scene reconstruction
- CeBIT america 2003**, New York (US), June:
Autostereoscopic 3D display
- LASER 2003**, Munich (DE), June:
Photonic components for industrial applications
- TDLS 2003**, Zermatt (CH), July:
Semiconductor DFB Lasers for industrial applications
- BMBF – Tag der offenen Tür**, Berlin, August:
Autostereoscopic 3D display
- IFA 2003**, Berlin, August/September:
PC-based Mixed-Reality working place
Autostereoscopic 3D display
MPEG-7 based image retrieval
Free2C display
Autostereoscopic 3D display
IM3DVC – Immersive 3D video conference
CineBox – Immersive projection for D-cinema
ImTV – Immersive TV by Head Mounted System
ATTEST – A 3D-TV system based on video plus depth information adaptive streaming
Travis 3D – Traffic visualization
3D reconstruction, and multiview video
MPEG-4 facial animation
Using DVB-T for IP-streaming
H.264/AVC video streaming using the Internet and mobile channels
- HiCon³²**, High-Quality Video image converter software for Win32 PC-platform
Multistandard display unit, audio/video processor for multimedia applications
- IBC 2003**, Amsterdam (NL), September:
CineBox – Immersive projection for D-cinema
MPEG-4 facial animation
H.264/AVC – Adaptive end-to-end Internet streaming solution
MPEG-4 video codec ASIC for mobile applications
HiCon³² video converter
- ITG/FKTG-Fachtagung**, Dortmund (DE), September:
HiCon³², Software tool for motion compensated video format conversion
- ECOC 2003**, Rimini (IT), September:
Novel semiconductor-based all-optical 3R regenerator (Live demonstration at 40 Gbit/s)
- CoIT** – Communication & Information Technology (Volkswagen), Wolfsburg (DE), October:
Free2C Display
- Sicherheitsmesse 2003**, Zürich (CH), November:
High level suspicious behaviour detection

COMMITTEE ACTIVITIES

- Standardisation Committees**
DIN
DVB Technical Module: Member
DVB-AVP: Member
DVB-H: Member
DVB-UMTS: Member
IPC-Standard (J-STD-040, "Optoelectronic Assembly and Packaging Technology, OPTOELECTRONICS ASSEMBLY SUBCOMMITTEE, 5-25"): Member
ISO/MPEG
ISO/MPEG AHG: Chair
ITU-T: SG 16, Associated Rapporteur
JVT: Co-Chair
- Research Program Committees**
COST 266, Progress of Photonic Infrastructure towards the IT-Age: Member
MCM
IST (Inform. Society Technologies): Evaluator
- Conference and Workshop Program Committees**
CLEO Technical Program Committee: Member
ECOC Technical Program Committee: Member

COMMUNICATIONS AND EVENTS

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

European Leica Beamwriter Users Meeting: Chairman

Human Factors in Telecommunications: Permanent Steering Committee

International Picture Coding Symposium: Steering and Program Committee Member

OFC Technical Program Committee: Member

Packet Video Workshop: Program Committee

Potsdamer Film Kolleg: Program Committee

Review Committee WIAMIS

SPIE Conf. on Visual Communications and Image Processing, VCIP 2003: Scientific Committee

Technisch-Wissenschaftliches Forum IFA '03

VTC Spring 2003 TPC: Member

Workshop on Immersive Communication and Broadcast Systems, ICOB 2003

Editorial Boards

IEEE ICME Track Chair

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

Springer Verlag Berlin, Heidelberg, Series "Optical Fiber Communication": Co-Editor

Other Committees

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

FKTG, Urtel-Preis-Komitee: Curatorship

ITG, FA 3.1 Fernsehtechnik und elektronische Medien: Chairman

ITG, FG 3.1.2 Digitale Bildcodierung: Chairman

ITG FG 5.2.5 Access- und Inhouse-Netze: Member

ITG, FA 5.3 Optische Nachrichtentechnik: Member

ITG, FG 5.3.1 Modellierung photonischer Komponenten und Systeme: Committee Member

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Münchner Kreis, Supranational Association for Communications Research: Research Committee and Conference Program Committee

OPTEC BB, Berlin: Member

VISNET: Executive Board

EXCHANGE PROGRAM

Scientists Visiting HHI

H. Chen, Southeastern University Nanjing, Nanjing (CN) financed by DAAD, for three months

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

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

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

F. Hopfer, TU Berlin, financed by TUB, for one year

J. Kim, Yonsei-University, Seoul, (KR), for one month

Andreas Kortke, TU Berlin, financed by TUB, for one year

V. Kravcenko, TU Berlin, financed by TUB, for eight months

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

T. Oechtering, TU Berlin, financed by TUB, for one year

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

B.C. Schumitsch, Stanford University, Stanford (US), financed by Stanford University, for three months

M. Vu Doan, Institute of Material Science, NCST, Hanoi (VN), financed by NCST for two months

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

HHI Scientists Visiting Foreign Institutes

A. Festtag, TU Berlin, financed by HHI, for five months

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