Fraunhofer
Heinrich Hertz Institute

FRAUNHOFER INSTITUTE FOR TELECOMMUNICATIONS, HEINRICH HERTZ INSTITUTE, HHI

ANNUAL REPORT
2016 / 2017 / 2018

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PREFACE

Fraunhofer HHI explores and develops technologies for tomorrow's digital society. The research areas of the Institute are Machine Learning, Video Coding, Vision and Imaging Technologies, Wireless and Optical Communication Networks, Photonic Components, and Sensor Technology. Fraunhofer HHI contributes significantly to research of great international relevance as demonstrated by its large number of scientific publications, the development of technological components, and contributions to the development of standards. The Institute collaborates with an extensive national and international network of partners from industry and science.

During the period covered by this report, Fraunhofer HHI was successful in continuing and expanding its record of scientific and economic accomplishments.

Activities in the field of Machine Learning were considerably expanded, both in terms of fundamental research and applications, for example in health and mobility. In the field of Video Coding, the Institute continued to participate in international standardization processes. Consistent progress was made in the field of Vision and Imaging Technologies that included founding a company for the acquisition of volumetric video data and its 3D modeling. Thanks to the successful work in Wireless Communications and strong growth of this research field at Fraunhofer HHI, a large number of research and standardization contributions to 5G and beyond have been made.

About 16.2 million euros were invested in InP technology within the framework of the Research Fab Microelectronics Germany (Forschungsfabrik Mikroelektronik Deutschland, FMD). In the research field of quantum technology, photonics researchers at Fraunhofer HHI succeeded in acquiring the first EU projects on quantum cryptography. In terahertz sensor technology, significant improvements in technological performance of sensors have been achieved that facilitate new industrial applications such as layer thickness measurement. In January 2018, four former employees founded the spin-off "FiSens" based on a newly developed high-resolution fiber-optic integrated spectrometer. Finally, the development of optical edge cloud networks was launched by a large German consortium to support future low-latency 5G applications.

THE HEINRICH HERTZ INSTITUTE CELEBRATED ITS 90TH ANNIVERSARY IN 2018

The Heinrich Hertz Institute, named after the famous German physicist of the 19th century, was founded over a period of several months in the 1920s. Prof. Karl Willy Wagner was appointed director of the newly founded Heinrich Hertz Institute for Oscillation Research on August 1, 1927. However, the formal establishment of the Institute was not complete until it received the seal of the Prussian Minister for Sciences, Arts and Public Education on February 23, 1928. In 2003, the Institute became part of the Fraunhofer-Gesellschaft.

To commemorate the anniversary, Fraunhofer HHI publicized a weekly highlight series of 90 years Heinrich Hertz Institute during the "birthday month" February 2018. These articles introduced important personages and events of the Institute, such as the reconstruction after the Second World War, the transformation into a GmbH, and the integration into the Fraunhofer-Gesellschaft. The articles also provided an overview of the recent outstanding technologies that were developed in the research history of the Institute, such as automatic image recognition, the coming 5G mobile communication standard, the OmniCam-360 system providing live video in a panoramic format, Li-Fi as a Visible Light Communications (VLC) technology, 3D Human Body Reconstruction (3DHBR) , High Efficiency Video Coding (HEVC), and many more. The highpoint of the celebrations was the Technology Innovation Science Match on February 22, 2018. In cooperation with the Berlin daily newspaper "Tagesspiegel", the Institute celebrated "90 years of excellent research for the digital society of the future" with more than 700 guests at KOSMOS Berlin. As part of the event, 24 internationally renowned scientists presented their current research projects and results to the guests. The ten-minute presentations focused on the main research fields of Fraunhofer HHI: video technology and the acquisition, transmission, and processing of data.

We would like to warmly thank all employees of Fraunhofer HHI, our Board of Trustees, the Fraunhofer-Gesellschaft, as well as our industrial partners, the public funding at state and federal level, and the European Union for their effort, confidence, and support.

1 *Prof. Dr. rer. nat. Martin Schell and Prof. Dr.-Ing. Thomas Wiegand, Executive Directors of Fraunhofer HHI.*

2 *Prof. Thomas Wiegand (center) and Prof. Martin Schell (right) with Tagesspiegel publisher Sebastian Turner (left) at the Technology Innovation Science Match.*

THE FRAUNHOFER-GESELLSCHAFT

● Main locations
○ Other locations

The Fraunhofer-Gesellschaft is the leading organization for applied research in Europe. Its research activities are conducted by 72 institutes and research units at locations throughout Germany. The Fraunhofer-Gesellschaft employs a staff of more than 26,600, who work with an annual research budget totaling 2.6 billion euros. Of this sum, 2.2 billion euros is generated through contract research. Around 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. International collaborations with excellent research partners and innovative companies around the world ensure direct access to regions of the greatest importance to present and future scientific progress and economic development.

THE FRAUNHOFER HEINRICH HERTZ INSTITUTE HHI

The Berlin-based research institute was founded in 1928 as the Heinrich Hertz Institute for Oscillation Research. The Fraunhofer HHI, with its focus on digital infrastructure has been part of the Fraunhofer-Gesellschaft since 2003.

INNOVATIONS FOR OVER 90 YEARS

Throughout its history, Fraunhofer HHI has often produced results with global impact. Recent successes include that every second bit on the Internet is touched at two points by Fraunhofer HHI technologies:

- Nearly 50% of bits transported via the Internet are compressed using the H.264/AVC video coding standard, significantly co-developed by Fraunhofer HHI.
- There is a 50% chance that a bit on the Internet will be transmitted with a core photonic component developed at Fraunhofer HHI, and probably built in the clean room of the Institute.

The diversity of the research topics at Fraunhofer HHI is reflected by the setup of the Institute's departments. Around 570 researchers work at three sites in the areas of Photonic Networks and Systems, Photonic Components, Fiber Optical Sensor Systems, Wireless Communications and Networks, Vision and Imaging Technologies, as well as Video Coding and Analytics.

1 *Overview of Fraunhofer institutes and research facilities in Germany.*

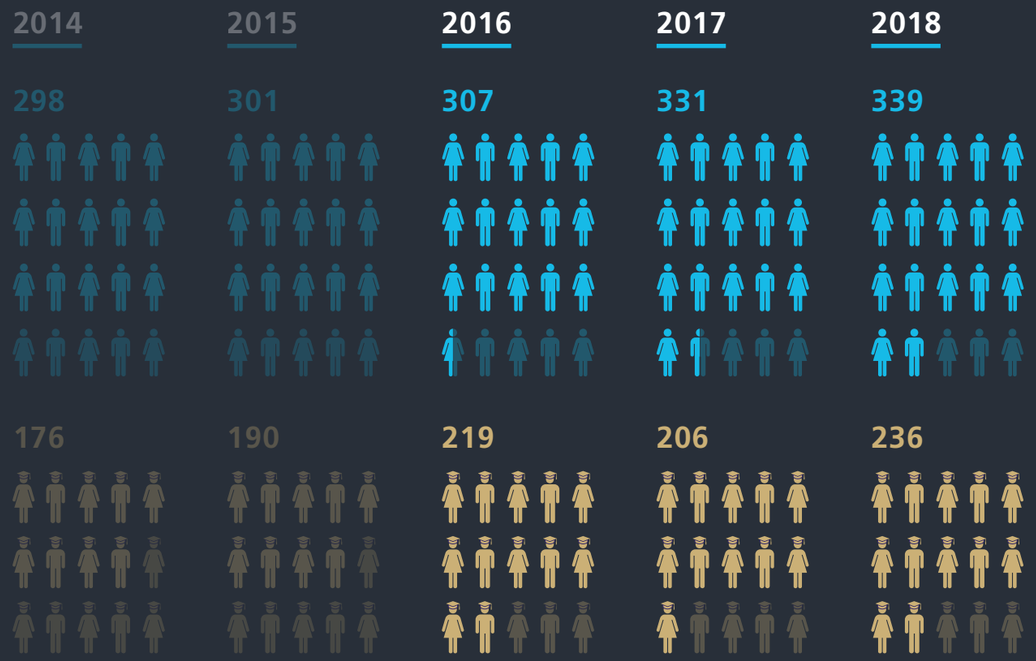
2 *The Fraunhofer HHI building in Berlin.*

FACTS AND FIGURES

ABOUT THE FRAUNHOFER HHI

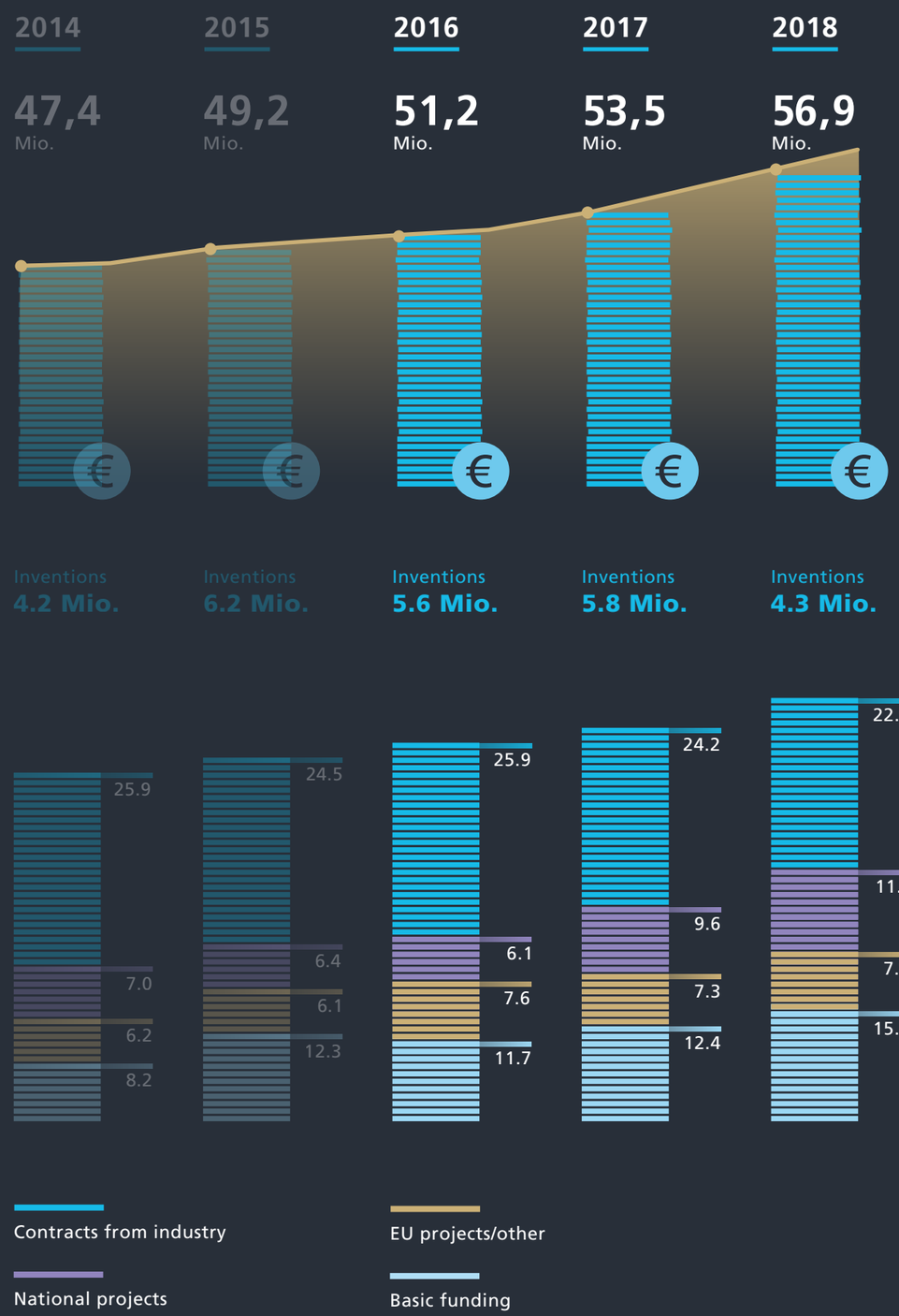
STAFF

IN PERSONS



BUDGET

IN EUROS



UNIVERSITY CHAIRS & SEMINARS

TECHNISCHE UNIVERSITÄT BERLIN

Image Communication
Prof. Dr.-Ing. Thomas Wiegand

Optics and Optoelectronic Integration
Prof. Dr. rer. nat. Martin Schell

Network Information Theory
Prof. Dr.-Ing. Slawomir Stanczak

Photonic Communication Networks
Prof. Dr.-Ing. Ronald Freund

Private lecturers:
Priv.-Doz. Dr. rer. nat. Volker Jungnickel
Priv.-Doz. Dr.-Ing. Oliver Schreer

HUMBOLDT-UNIVERSITÄT ZU BERLIN

Visual Computing
Prof. Dr.-Ing. Peter Eisert

CLAUSTHAL UNIVERSITY OF TECHNOLOGY

Applied Photonics
Prof. Dr. rer. nat. Wolfgang Schade

Special professorial appointment
apl. Prof. Dr. Eike G. Hübner

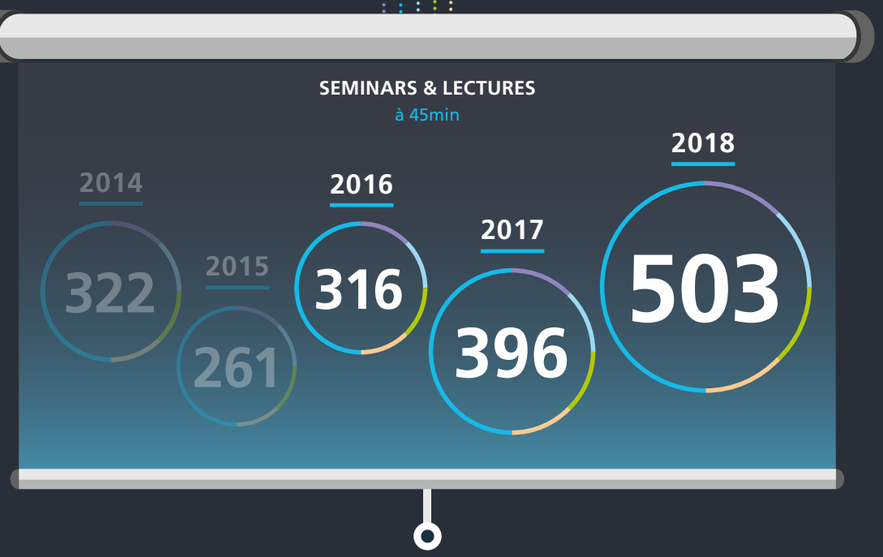
FREIE UNIVERSITÄT BERLIN

Image Signal Processing
Prof. Dr.-Ing. Heiko Schwarz

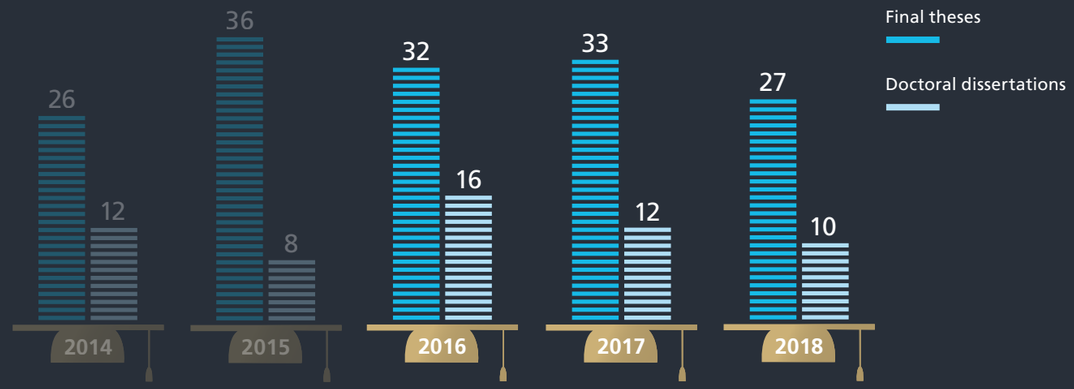
UNIVERSITY OF POTSDAM

Embedded Systems Architectures for Signal processing
Prof. Dr.-Ing.
Christian Benno Stabernack

SEMINARS & LECTURES
à 45min

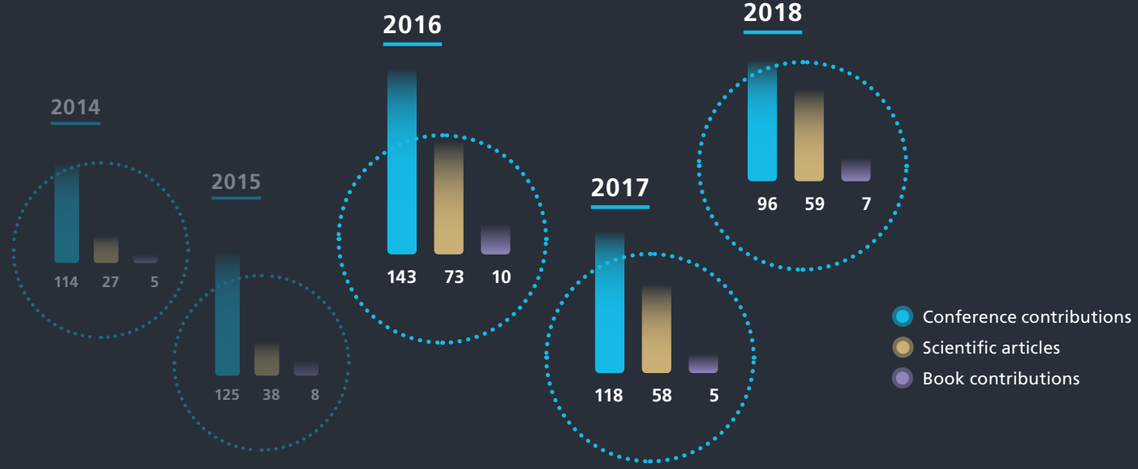


THESES

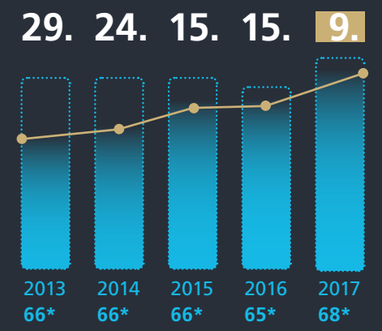


SCIENTIFIC EXCELLENCE

PUBLICATIONS



9TH PLACE
AMONG ALL FRAUNHOFER INSTITUTES



* Number of institutes in the Fraunhofer-Gesellschaft

BOARD OF TRUSTEES

The board of trustees advises the Executive Directors of the Institute and promotes contacts of the Institute to organizations and to the industry.

Prof. Dr.-Ing. Klaus Petermann,
Institute of High-Frequency and Semiconductor System Technologies, Chairman of the Board of Trustees, Technische Universität Berlin

Dr.-Ing. Werner Mohr,
subst. Chair of the Board of Trustees,
Head of Research Alliances,
Nokia Solutions and Networks GmbH & Co. KG

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Dr. Christian Winkler,
Head of Research & Senior Principal,
Siemens AG, Corporate Technology

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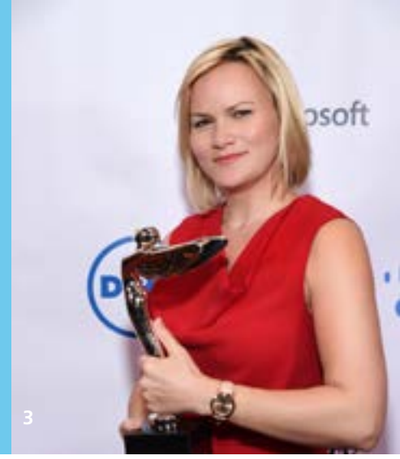

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NETWORK AND AWARDS

Fraunhofer HHI has an international focus and is also closely linked with the German research landscape.

Member of Fraunhofer Groups:

- Microelectronics
- Information and Communication Technology ICT (guest)
- Defense and Security VVS (guest)

Member of Fraunhofer Innovation Clusters:

- Life Cycle Engineering for turbo-machines
- Next-Generation ID

Member of Fraunhofer Alliances:

- Ambient Assisted Living (AAL)
- Battery
- Big Data and Artificial Intelligence
- Digital Media
- Space
- Vision (Image Processing)

Between 2016 and 2018, the following scientists at Fraunhofer HHI were honored for their research work in various fields:

Förderpreis-ARD/ZDF: Fraunhofer HHI scientist Anna Hilsmann was voted among the top three with her thesis "Image Based Approaches for Photo Realistic Rendering of Complex Objects". She ranked second for the ARD/ZDF "Frauen + Medientechnologie" (Women + Media Technologies) Award in 2016.

AMA Innovation Award: The development team at the Fraunhofer HHI and the Photonik Inkubator Niedersachsen received the 2016 AMA Innovation Award for their project "Nerves of Glass - Fiber-Optic 3D Positioning of Heart Catheters".

Primetime Engineering Emmy Award: In 2017, the Institute celebrated its fourth Emmy together with Huawei, MediaTek, Nokia, Qualcomm Incorporated, Samsung and Sony Corp. for the development of the HEVC standard. HEVC allows videos to be transmitted efficiently in ultra-high definition.

AIS Distinguished Leadership Award: In 2018, the Advanced Imaging Society (AIS) selected 13 individuals whose work was exemplary in advancing the industry. Kathleen Schröter, Head of Corporate Communications at Fraunhofer HHI, was the first European woman to receive this award.

Leopoldina: On the recommendation of renowned colleagues from the academy, the Executive Committee of the Leopoldina elected Prof. Dr.-Ing. Thomas Wiegand as a member of the Academy. He is in the Information Sciences section.

1 *Anna Hilsmann (left) at the award ceremony for the Förderpreis-ARD/ZDF "Women + Media Technologies".*

2 *The HEVC researchers of Fraunhofer HHI Benjamin Bross (left) and Detlev Marpe at the Emmy Award Ceremony in Los Angeles.*

3 *Kathleen Schröter with the Distinguished Leadership Award.*

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RESEARCH FAB MICROELECTRONICS GERMANY

More information about the FMD can be found here.

Technology expertise from a single source and coordinated Germany-wide

Fraunhofer HHI is one of 13 members of the Research Fab Microelectronics Germany (Forschungsfabrik Mikroelektronik Deutschland, FMD). Over 2000 scientists make FMD Europe's largest cross-site R&D consortium for Micro- and Nanoelectronics.

This innovative partnership links the advantages of two leading distributed research organizations, Fraunhofer-Gesellschaft and the Leibniz Association, yet with the synergies of one centralized organization, to form the world's most high-performance service provider for applied research, development and innovation in the field of Micro- and Nanoelectronics. FMD's tight interconnection and cohesive presence mean it can provide comprehensive and simplified access to next-generation technologies – not only to major industrial customers, but also in particular to SMEs and start-ups.

The Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF) is supporting the establishment of the FMD with a total of 350 million euros in funding to be devoted primarily to the modernization of the member institutes' research facilities. The BMBF intends this funding to help strengthen the innovative power of the semiconductor and electronics industries in Germany and Europe in the context of global competition. The funding represents the largest investment in research equipment since German Reunification. Only a year after the project launch on April 6, 2017, many of the acquisitions for modernization of the laboratory facilities at FMD sites throughout Germany have already been put into operation. The launch of the first fab line was held with a symbolic gala ceremony, at the Fraunhofer Institute for Reliability and Microintegration IZM, on September 28, 2018, as part of the first FMD Innovation Day. With the project having reached the half-way point, about 45 percent of the planned investments for FMD have been implemented successfully.

The ongoing expansion of FMD is coordinated at a central administrative office in Berlin. In keeping with the intention of creating a virtual organization, additional sites have been established in Dresden and Munich. The FMD administrative office is the central point of contact for potential and existing customers and is thus an essential business development driver in the field of Micro- and Nanoelectronics.

In order to offer coordinated technology and system developments from a single source Germany-wide, the technological expertise of the Fraunhofer member institutes has been consolidated and further enhanced in six interdisciplinary areas during the initial setup phase. These are designated the technology platforms Microwave and Terahertz, Power Electronics, Extended CMOS, Optoelectronic Systems, Sensor Systems and MEMS Actuators. The FMD provides technological developments along the entire value chain of these technology platforms.

In addition to this technology-oriented service range, the FMD offers cross-institute application solutions from a single source. This makes it possible for customers to implement combined and optimized system solutions in partnership with FMD and its institutes, based on the synergies generated in the FMD through collaboration among the institutes' business areas across institute boundaries.

Project participation was successfully allocated and assignments completed in collaboration with the FMD last year. Projects with a total budget of 41.1 million euros based on FMD investments have already been defined for 2018 – a major success at this early stage. Industry's share in this project budget has already reached 30 percent, highlighting the significance to industry of this unique German Microelectronics research partnership.

FMD will enter a new phase in 2019. With the establishment and structural development of the organization completed, the largest cross-site research and development (R&D) collaboration for Micro- and Nanoelectronics in Europe will now prove its ability to compete in the market.

1 *Regional launch event for the FMD with former Federal Minister Johanna Wanka and Fraunhofer HHI Executive Director Prof. Dr. rer. nat. Martin Schell.*

FRAUNHOFER HHI
RESEARCH HIGHLIGHTS

Pioneering technologies and solutions

The research highlights of the last three years reflect the strategic orientation for the future of the Fraunhofer HHI. The Institute pursues applied research in the broad spectrum of communication technologies. In this context, interdisciplinary approaches are becoming increasingly important. As a result, researchers are increasing their efforts in interdepartmental projects. This is particularly apparent in activities related to Artificial Intelligence, Quantum Communication, Li-Fi, Augmented and Mixed Reality, Image Analysis, Industry 4.0, and medical applications.

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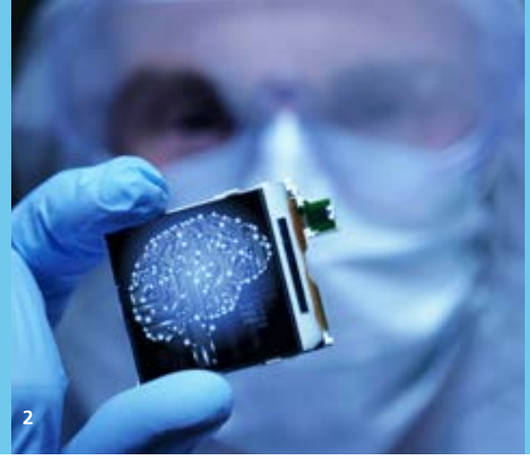

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ARTIFICIAL INTELLIGENCE FOR HEALTHCARE AND COMMUNICATION TECHNOLOGIES

In the near future, Artificial Intelligence (AI) will create new technologies and make it possible to improve existing technologies in many fields of application. Work by Fraunhofer HHI has contributed major advances in theoretical and algorithmic research, implementation, and standardization of AI.

AI at Fraunhofer HHI

Fraunhofer HHI has investigated the use of AI in the analysis of health-related data sets such as neural data from electroencephalograms (EEG), heart rate data from electrocardiograms (ECG), and medical imaging data. Findings showed, for example, that neural networks can predict heart attacks based on ECG data just as well as experienced cardiologists can. Fraunhofer HHI is also currently researching ways to improve the analysis of medical imaging data from computer tomography, magnetic resonance imaging, functional magnetic resonance imaging, and mass spectroscopy. The analysis of medical imaging methodologies is particularly challenging because of the high dimensionality of the data, its spatiotemporal correlations, missing data, and relatively small sample sizes. Fraunhofer HHI is therefore developing frameworks based on deep learning to meet these challenges.

A substantial amount of the data transmitted via the Internet consists of multimedia signals that can suffer loss of quality due to compression, transmission losses due to interference, and quantization errors. Since these video and audio signals are usually intended for humans, the subjectively perceived quality after transmission is key. Fraunhofer HHI uses EEG data to objectively assess quality as perceived in multimedia systems, then applies Machine Learning to optimize video encoding specifically for perceptual quality.

Wireless communication (including 5G) is opening up further opportunities for applying Machine Learning. Because of their high mobility, wireless connections are transient and dynamic. They can also be adversely affected by noise or subject to signal interruptions. Moreover, the resources (i.e. the spectrum and energy) are limited. These factors can restrict the capacities of wireless networks.

The algorithms developed by Fraunhofer HHI make self-organizing networks possible, while at the same time maximizing energy savings. Hybrid procedures combining purely data-driven algorithms for Machine Learning with classical model-based approaches have proven particularly successful here. The integration of high-performance edge-cloud servers in the network makes further progress possible in the areas of online learning (i.e. learning at data input) and the virtualization of network functions.

Explainable AI creates trust

Transparency of the optimized systems is necessary in all these AI application areas. In the field of medicine, for example, assistance systems are being learned on a training set in order to support the physician's diagnostic work by providing a recommendation based on the specified data. In a task such as this, transparency in the form of an explanation of the underlying basis of the AI analysis is an absolute necessity, since an incorrect diagnosis could have fatal consequences. Working together with the Technische Universität Berlin, Fraunhofer HHI developed what is called the "Layer-Wise Relevance Propagation" process. This process lets the user go backwards through the complex networks of an AI algorithm in order to reach the point at which a prediction has been made in order to identify the input components that constitute the prediction. Referred to as Explainable Artificial Intelligence (XAI), this generates the necessary confidence in AI predictions in those areas that have no margin for error, such as medical diagnostics.

Privacy through distributed learning

Data protection and protection of privacy are decisive factors in many applications, especially those in health care. As a result, the data necessary for AI training is not always all available at a single location. Distributed learning processes being researched at Fraunhofer HHI make it possible to implement Machine Learning on different devices, each of which has access to different data. The individual algorithmic models are combined to form one overall model with improved quality without the need to release or transmit potentially sensitive data.

Paradigm shift in health-care and communication technologies

The current state of research points towards a new paradigm that will result in a stronger presence of AI. When properly applied, AI can assist in the identification, segmentation, classification, diagnosis and effective treatment of illnesses. Fraunhofer HHI has a large number of projects and activities focusing on the support in healthcare, such as the focus group "AI for Health" (FG-AI4H), the Berlin Center for Machine Learning (BZML) and AI applications for health-related data sets and imaging processes. The FG-AI4H is a partnership between the International Telecommunication Union (ITU) and the World Health Organization (WHO), including members from the health and technology sectors as well as government supervisory authorities. The objective of FG-AI4H is to create a platform using standard systems for detailed evaluation of AI algorithms in healthcare. Fraunhofer HHI supports this goal with guidance, organization and technical assistance in the selection of appropriate training data for the evaluation of AI algorithms as well as expertise in XAI. The BZML researches methods for integrating a priori knowledge into learning processes in order to make models more reliable and robust, answering a criticism levelled at AI. In collaboration with the BZML „Biomedicine" cluster, Fraunhofer HHI helps to address questions of data quality (i.e. small data sets, multi-modality and missing data) and on the transparency of AI applications, for example, in histopathology.

In the years to come, new AI challenges will emerge in healthcare, wireless communication, image processing, and many other fields. Fraunhofer HHI is well-positioned to meet these challenges and remains a leader in the fields of AI and Machine Learning.

1 *Current progress in AI is based on data-driven learning algorithms.*

2 *Many methods in AI are inspired by neural processes in the brain.*

3 *AI is driving a paradigm shift in healthcare.*

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QUANTUM TECHNOLOGIES AT FRAUNHOFER HHI

At a glance

Digitalization is penetrating our entire society, from Industry 4.0 to healthcare to critical infrastructure. In this process, data security and secure communications are becoming increasingly essential. Quantum Key Distribution (QKD) is a very promising approach here: It uses quantum states as an information carrier that, because of fundamental laws of physics, can neither be copied nor intercepted without detection. QKD is the most advanced quantum technology. In principle, it allows communication that is absolutely impervious to eavesdropping. The Fraunhofer HHI has defined the objective of converting this theoretically viable security system into a practical one. A prerequisite here is high-precision components capable of manipulating only a few or even single photons and atoms. In addition, completely new components are to be developed which are either based on quantum effects or are capable of measuring them.

The Fraunhofer HHI departments Photonic Networks and Systems and Photonic Components are working with national and international partners to develop components and systems that move quantum communications further towards broader market readiness. Fraunhofer HHI addresses various aspects, ranging from development of photonic integrated chips and QKD systems to networks supported by quantum transmitting repeaters.

Innovative QKD protocol

The Collaborative Research Center (Sonderforschungsbereich, SFB) 787, "Semiconductor Nanophotonics: Materials, Models and Devices" of the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) brings together three universities and four research institutes in Berlin and the vicinity. They are investigating various topics in the area of optoelectronic components and nanomaterials. Fraunhofer HHI has implemented the time-frequency QKD protocol, based on the time-frequency uncertainty of individual light quanta. This uses mostly components from conventional communications technologies to create a functional demonstrator. Using existing expertise in free-space optical laser communication, optical antennas were developed and used to demonstrate QKD from one building to another at Fraunhofer HHI. Another project goal is improving the wavelength-multiplexing of quantum communications and classical transmission channels for existing fiber-optic communication networks. Because of high-dimensional encoding capability and compatibility with existing technologies, the time-frequency protocol offers advantages compared to other QKD protocols and can be used in fiber optics as well as in free-space optical communications.

Quantum repeaters allow larger transmission distances

Fraunhofer HHI is one of 24 partners that have come together in the project Q.Link.X to develop key technologies for quantum repeaters (QR). The objective of Fraunhofer HHI is the provision of an application-related test environment of installed fiber-optic lines for testing the jointly developed QR components, QR cells and QR segments. Here, the quantum advantage is to be demonstrated by the use of QRs over longer transmission distances. The laboratories of Fraunhofer HHI are connected to installed fiber-optic lines for this purpose. The three different technology platforms – quantum dots, diamond color centers and a combination of atomic and ionic systems – are to be used to implement transmission segments of between ten and one hundred kilometers to compare the advantages of the respective systems with one another.

Quantum technology for everyone

Another challenge the institute addresses is making quantum communications available to everyone. This primarily requires miniaturization of the components needed for QKD. Impressive results are already emerging in secure transmission of encryption keys using QKD. These results are usually achieved in major laboratory facilities with optical free-space components which are inherently expensive and difficult to integrate. At present, this still greatly limits the practical applicability of QKD in existing fiber-optic networks. This is where the Fraunhofer HHI department of Photonic Components comes into play. Based on decades of expertise in the field of optoelectronic telecommunications components, it is developing integrated optical chips for various QKD protocols.

Fraunhofer HHI participates in two consortiums as part of the Quantum Flagship, in which the EU will invest one billion euros over the next ten years to increase its competitive strength in this future-oriented field. CiViQ is a project that develops coherent QKD receiver chips based on InP technology. In the project UNIQORN, the PolyBoard platform is used for the hybrid photonic integration of optical waveguides, micro-optical components and non-linear optical crystals. This makes it feasible to miniaturize successful experiments from the optical bench all the way into integrated photonic chips. Both projects include renowned partners from research and industry to lay the foundations for realizing "quantum technology for everyone" within the next few years.

1 *Quantum communications: A highly promising approach to data security and secure communication.*

2 *PolyBoard ppLN hybrid subunit with passive, single-mode fiber coupling; ppLN optical medium chip from Paderborn University.*

At a glance

Future applications in converged 5G networks (Smart Cities, industrial automation, cloud services, autonomous driving and telemedicine) require a high-performance, scalable, flexible and secure optical-fiber infrastructure.

So far, transmission capacity has been allocated statically in the networks – leading to over-allocation and making dynamic allocation of network resources with low latency impossible.

1 ***Optical fiber-based subsystems for configurable, flexible data-rate, optical transmission systems using multiple wavelength bands.***

2 + 3 ***Test laboratory for terabit-per-second data transmission in elastic optical communications networks.***

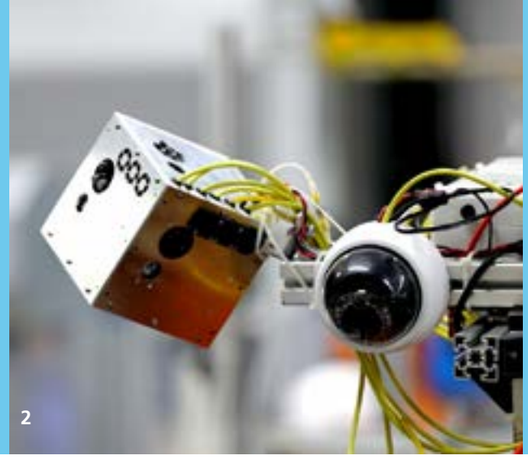
ELASTIC OPTICAL NETWORKS WITH SCALABLE CAPACITY AND LOW LATENCY

Efficient use of fiber optics

Fraunhofer HHI develops innovative solutions using elastic optical-fiber networks with flexible capacity of terabit/s and a transmission range of up to several thousand kilometers. Moving from static network topology towards demand-driven allocation of bandwidth resources at the optical layer makes it possible to more efficiently use the installed optical-fiber infrastructures by employing capacity reserves. The objectives of current research are software-configurable optical transmission systems with adaptable data rates capable of providing transmission capacities for each channel at fine granularity up to the terabit/s range. Application areas can be found both in wide-area networks and in the field of regional metro networks.

Increasing transmission capacity

In addition to the new requirements relating to latency, the overall need for transmission bandwidth has continued to grow over the last few years. The upcoming introduction of 5G wireless communication networks is expected to cause a dramatic increase of the annual growth rate of optical network traffic. Fraunhofer HHI is therefore working on optical transmission systems that make it feasible to use the entire available bandwidth of single-mode optical fiber transmission. At present, commercial systems usually operate only at a single wavelength or band and thus use only around ten percent of the available bandwidth. Expansion into the unused wavelength bands promises greater efficiency and a comparatively cost-effective increase in transmission capacity, since it will be possible to continue using the existing optical-fiber infrastructure. This will allow network providers to seamlessly scale up the capacities of their fiber-optic networks through modular exploitation of additional wavelength bands. Here, Fraunhofer HHI is working both on system optimization of these multiband systems and on the development of innovative subsystems and photonic components in order to realize the vision of increasing transmission bandwidth of the existing optical-fiber infrastructure by a factor of ten.



NETWORKED DATA TRANSMISSION WITH VISIBLE LIGHT

At a glance

As a wireless medium, light is secure by its very nature: Light does not pass through walls and communication is only possible within the light cone. Furthermore, light is robust against electromagnetic interference, i.e. it cannot be interfered by radio waves. Reliability can be effectively increased in the case of shadowing by using several transmitters and several receivers (Multiple Input Multiple Output, MIMO). In connection with adaptive, distributed MIMO protocols mobile applications with low latency can be supported.

1 *Li-Fi pilot installation in manufacturing environment.*

2 *Detail view: Li-Fi module mounted on a robot arm.*

3 *Li-Fi pilot installation in a classroom.*

Li-Fi for Industry 4.0

Industry 4.0 will support more flexible manufacturing of increasingly personalized products in smaller unit quantities. In the industrial Internet of Things (IoT), mobile robots and tools will communicate via wireless connections. Moreover, they will be dynamically networked through Artificial Intelligence in a cloud infrastructure. Continuous production will require wireless transmission at levels of security, reliability and latency similar to those of cable-based data connections.

As part of the OWICELLS project, funded by the Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF), the use of Li-Fi was investigated with the objective of modernizing production technologies in the automotive industry. Fraunhofer HHI has developed a new concept based on the distributed Multiple Input/Multiple Output (MIMO) approach that supports reliable transmission in mobile scenarios. Here, a first prototype system is being developed based on inexpensive LEDs and exploiting the license-free spectrum of visible and infrared light for mobile data transmission. A Li-Fi solution based on MIMO was successfully demonstrated in a pilot installation at the BMW factory plant in Munich. This robust, optical transmission is primarily based on spatial distribution, i.e. data are sent and received by several LEDs and several photodiodes at the same time. The optical system can reliably transmit data in real time at more than 100 Mbit/s and with less than five milliseconds latency. The system has thus proved its high reliability in the execution of typical industrial tasks such as spot welding with high voltages and arc welding.

Li-Fi in schools

Demand for wireless communication in buildings will increase in the years to come. Li-Fi will be an interesting supplement to RF-based solutions because it supports a large number of broad-band access points for multiple users. With only a few additional components, conventional LED light sources can be turned into high-power transmitters for optical WiFi. This approach supports data rates of more than one gigabit per second, which can be used in the transmission of high-quality video data at HD and 4K quality, for example.

The digital classroom of the future will require capability for the simultaneous exchange of data from many students with the Internet. Here, Fraunhofer HHI is working together with the "Hegel-Gymnasium" high school in Stuttgart, for example on a Li-Fi classroom that can be used for a variety of teaching styles. This pilot installation makes it possible to test and adapt Li-Fi technology for applications in the educational sector.

DIGITAL TWIN - NETWORKED XR FOR CONSTRUCTION 4.0

At a glance

Virtual, Augmented and Mixed Reality (VR/AR/MR) technologies have increased enormously in recent years. This is due to the major scientific and technological advances in the fields of 3D scene capture, tracking, and eyewear technologies.

The latest generation of VR and AR glasses allow users to navigate in virtual worlds almost latency-free. These advances open up a multitude of new application areas with enormous potential in various market segments such as Industry 4.0, medical technology, infotainment and edutainment as well as in the media sector. The realization of this market potential requires efficient wireless networking that cannot be adequately provided by classical wireless technologies. Thus, the development and installation of a 5G- and Beyond 5G-communication infrastructure has high priority. It needs to be tailored to the requirements of VR/AR applications for the essential high data rates and reliability as well as low transmission delays.

1 ***Example of a supporting structure in facade construction.***

2 ***Prototype of a steel node from facade construction.***

3 ***Exact positioning of the steel node using virtual guidance in the AR glasses, demonstrator at BAU 2019.***

The construction sector poses particular challenges for these technologies. The reasons for this are the high demand for robustness, simplicity of operation, use of the technology under difficult conditions and the lack of technical infrastructure on the construction site. At the same time, the potential demand for AR- and VR-based visualization technologies in this industry is very high. People on a construction site, for example, could be provided with helpful additional information using AR eyewear technology integrated into the construction helmet that would considerably facilitate assembly work. The areas of application cover all the phases of a building's life cycle, starting with the planning through production and assembly, to operation, maintenance and dismantling.

The Digital TWIN research project funded by the Federal Ministry for Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie, BMWi) deals with precisely these problems. Fraunhofer HHI and its project partners *se commerce, planen-bauen 4.0, Telegärtner, Zeiss 3DA and Werner Sobek Stuttgart* are developing a joint digital platform for all the companies involved in a building's life-cycle. The goal is to improve the interfaces between planning, production, assembly, operation and dismantling using IT-supported tools. Technical support via paperless construction sites using innovative AR/VR-based visualization and interaction methods and tools will be developed. AR eyewear technology systems integrated into the protective visor of construction helmets will enable the user to superpose additional information such as planning models and manufacturing instructions on the real world. New methods for 3D tracking, scene analysis and registration of CAD planning data on real scenes are being developed to enable AR visualization and verification of the current state. Communication with remote workstations will be maintained for the purpose of off-site monitoring and analysis.

Another important field of research is the use of new wireless technologies (5G) for the fast, low-latency and flexible networking of AR and VR devices on site. Different end-user devices need to be connected efficiently and meet the quality-of-service requirements. Due to the required transmission rates, a combination of classical frequency ranges used in mobile communications and millimeterwave technologies with large available bandwidths and inherent security must be considered.

In 2019, a first demonstrator of the Digital TWIN project was presented to the public at the BAU exhibition in Munich. A typical assembly situation was simulated by using a steel node from facade construction, which can be moved vertically, rotated and tilted (figures 2 and 3). A camera records the position and orientation of the component in real time and compares it with a reference model created in a CAD program. Thus, the exact position of the real object can be compared with the required position in the plan. When installing the steel node, the user is then provided with positioning instructions in the form of virtual arrows as a superposition of the real scene by means of AR glasses. This simplifies the assembly in practice considerably. The user then confirms the final position in compliance with the required tolerances.

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At a glance

Volumetric video is regarded worldwide as the next important development step in the field of media production. Volumetric video will become a key technology, especially in connection with the very rapid development of the Virtual Reality (VR) and Augmented Reality (AR) markets. Fraunhofer HHI researchers have developed a volumetric video technology named "3D Human Body Reconstruction" (3DHBR) that has already received multiple awards. This technology transfers the realistic image of a person into the virtual world.

1 Prototype of the first volumetric video studio on the European continent.

2 A look at the joint production with UFA "Ein ganzes Leben" ("A whole life").

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VOLUMETRIC VIDEO

From research to professional production

"3D Human Body Reconstruction" technology captures a real person with several cameras simultaneously in order to generate naturally moving, dynamic 3D models that can then be viewed from various perspectives in the virtual scene.
The capture system for volumetric video consists of 16 stereo cameras that capture 3D information of the person from all perspectives. This can be compared with three-dimensional sight of the human eye. The resulting 3D information is consolidated and integrated in a consistent, natural and dynamic 3D representation of the person.

Post-processing modules adapt the data structures and formats appropriately so that direct integration in standardized post-production processes and Virtual Reality software for VR glasses and AR applications is possible. In contrast to classical animation of virtual characters, facial expression and moving clothes are captured and reconstructed with a high degree of geometrical detail and high texture quality. This results in a highly natural visual impression. The processing is completely automatic.

In addition to processing dynamic 3D models, a new integrated multiple camera and lighting system has been developed for complete 360-degree acquisition of persons. The system supports diffuse lighting from any direction, automatic keying and flexible multi-camera arrangements. Elimination of green screen segmentation techniques and the provision of diffuse lighting from all directions results in excellent conditions for what is called re-lighting, the subsequent creative lighting of the 3D models in the virtual scene.

The first prototype of this new capture and processing system was built at Fraunhofer HHI in October 2017 (see figure 1). The first VR production to use volumetric video began in partnership with UFA GmbH film productions. This highly regarded film entitled "Ein ganzes Leben" ("An Entire Life") is an integral part of the permanent exhibition in the Filmmuseum at Potsdamer Platz in Berlin (see figure 2).

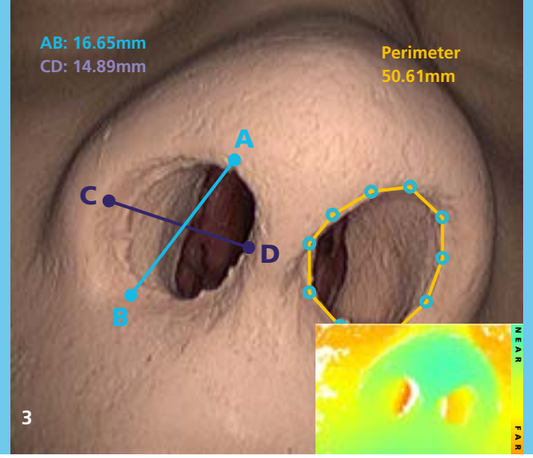
This and other test productions attracted a lot of attention in the Berlin-Brandenburg media industry. Hence, it was decided to transfer this technology to a commercial production environment. With the support of the State of Brandenburg's Ministry for Economic Affairs and Energy (Ministerium für Wirtschaft und Energie des Landes Brandenburg, MWE), the Fraunhofer-Gesellschaft formed the joint-venture Volucap GmbH together with the companies ARRI, Studio Babelsberg, Interlake and UFA.

In June 2018, the first volumetric studio on the European continent was then opened on the grounds of Studio Babelsberg. This new studio represents an improved version of the research prototype and uses the latest computer technologies. The studio has been producing commercial videos in a wide variety of genres, including entertainment, fashion, advertising and cultural heritage since November 2018.

At a glance

Minimally invasive procedures with endoscopes and surgical microscopes have become standard in surgery. This kind of medical procedure shortens the healing process and improves hygienic conditions to achieve improved surgical results. Nevertheless, this kind of surgical approach is highly resource-intensive, placing high demands on the operating room staff and the technology used.

This is why Fraunhofer HHI is investigating the use of computer vision algorithms for real-time intraoperative assistance and navigation functions that support the entire surgical process. In particular, the Institute is working on adapting interactive and multimodal Augmented Reality systems for computer-assisted ear, nose and throat surgery. Here, the processing pipeline uses digital stereoscopic cameras that support multispectral representations and white-light procedures for creating high-resolution image data. Multimodal image analysis, bi-directional interactive Augmented Reality (AR) and Mixed Reality (MR) are the subjects of the projects MultiARC, COMPASS and 3D-Horopter.



1 Digital surgical microscope with integrated Fraunhofer HHI measurement solution.

2 Mobile recording of replacement parts in industrial applications.

3 Image-based 3D measurements for intraoperative support.

MEDICAL AND INDUSTRIAL IMAGE ANALYSIS

Medical image analysis

Hybrid multi-modal 3D scene analysis uses different wavelengths to classify tissue structures, then combines this spectral data with 3D spatial information. The tissue samples are analyzed in the visible and near-infrared ranges (IR). In addition, an intraoperative software tool for the implantation of virtual ossicle prostheses (stapedectomies, for example) is used that guarantees 3D measurements of very high precision in the sub-millimeter range. In order to achieve these levels of precision, a zoom-independent calibration tool was developed. Fraunhofer HHI uses 3D reconstruction methods to create anatomical 3D maps for surgical navigation in human body cavities, since currently existing surgical navigation systems such as electromagnetic tracking and IR-based optical tracking systems are error prone with regard to external interference and line-of-sight interruptions.

In addition, image data is analyzed in order to detect and classify vital data such as pulse rate, local blood flow and local tissue deformation. All this information can then be displayed directly in the surgeon's field of view using a bidirectional interactive AR/MR communication module which provides meaningful information and thus avoids information overload. This type of collaborative surgical system offers a variety of advantages and will result in substantial improvements in patient results due to simplified, more precise and accurate tissue classification, reduced surgical stress and lower risk in operations. The digitalized processing chain also supports annotated video recordings of the operation for surgical training purposes and for comprehensive documentation of the surgical procedure for post-operative analysis.

Industrial image analysis

In the projects EASY-COHMO and M3D, seamless integration of AR visualizations is also used in industrial workflows to improve human-machine interaction and collaboration. The assistant system can perform time-consuming and hazardous tasks faster and with fewer risks.

A generic replacement-part identification system was developed in order to automatically identify industrial objects during maintenance. A mobile app lets the user record images of the object being examined and sends them to a cloud-based 3D reconstruction service for analysis and identification.

Projector-camera systems add additional information to real work environments, with robust object tracking ensuring spatially stable augmentation. The tracking system uses CAD models of visible components, registering their contour and texture information as well as the simulated reflection of the projection on the 3D object surface with the camera image. Fraunhofer HHI has developed a multi-sensor system that also features integrated gesture and hand recognition modules that facilitate immersive real-time interaction for performing inspection tasks in Industry 4.0.

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At a glance

The global growth rates of all types of Internet-based video data are unabated. Currently, the data traffic for Internet video is predicted to triple by 2022. As a result, the share of IP-based video in global data traffic is expected to exceed 80 percent by 2022.

Additionally, the proportion of household television sets with 4K resolution is projected to grow to almost two thirds. Thus, efficient coding, transmission, processing and analysis of increasingly higher-resolution video signals are becoming even more important.

VERSATILE VIDEO CODING (VVC)

The Fraunhofer HHI Video Coding and Analytics department covers all relevant aspects of the related research areas. In the past, it has made significant contributions to the H.264/MPEG-AVC and H.265/MPEG-HEVC international video coding standards in order to provide the key technologies for the increasing use of digital video in daily life. These contributions have been honored four times with an Emmy Award. The Emmy of the National Academy of Television Arts & Sciences is considered one of the most prestigious US television awards. In order to initiate work on a future successor standard to H.265/MPEG-HEVC, the ITU Video Coding Expert Group (VCEG) and the ISO/IEC Moving Pictures Expert Group (MPEG) published a Joint Call for Proposals for new video coding technology within the Joint Video Experts Team (JVET) in October 2017.

In April 2018, after Fraunhofer HHI and other leading technology companies submitted promising proposals for the HEVC successor and the standardization process for "Versatile Video Coding" (VVC), the HEVC successor, began. Fraunhofer HHI's proposal not only included continued development of already familiar technologies, but also included new compression methods that had been developed with the help of Machine Learning. Compared to HEVC, this proposal achieved a bit rate reduction of up to 40 percent for the same image quality. The Fraunhofer HHI proposal was among the best in all three evaluation categories (standard, high dynamic range and 360-degree video).

The VVC standardization phase began in April 2018. During this period, the best proposals are now thoroughly checked for complexity, compression efficiency, and their ability to be implemented before they are considered as part of the draft standard. Five of the techniques submitted by Fraunhofer HHI have already passed this test and qualified for the draft VVC standard. Others are currently being investigated further and continuously improved. The current compression efficiency of the draft VVC standard was already presented to an expert audience at the Fraunhofer booth at the Consumer Electronics Show (CES) in Las Vegas in January 2019. Experts and technologically oriented executives were amazed by a 4K video recording compressed with VVC that still displays impressive quality even at extremely low bit rates of 2 Mbits per second. The final version of the new VVC standard is planned to be officially approved in July 2020.

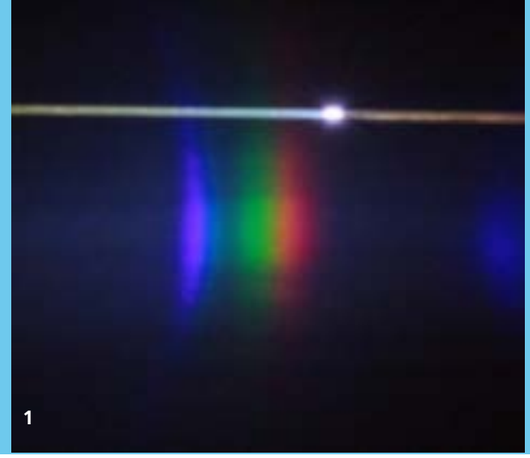
1 *Example for the new, extremely flexible block partitioning of VVC.*

2 *Mobile and high-resolution 4K video as a major application area for VVC.*

3 *One of four Emmys from Fraunhofer HHI awarded to VVC precessors.*

At a glance

A fundamental requirement for a successful implementation of digitization strategies in the industrial environment is the supply of suitable sensors. Optical sensors based on Fiber Bragg Gratings (FBG) can easily be adapted and integrated in a variety of industrial processes. A set of FBG sensors can be produced with high precision in a single-mode glass fiber at arbitrary positions, tailored for individual applications. This flexibility in combination with high quality standard of FBG sensors is enabled by our improved, automated processing technology applying femtosecond lasers. Optical FBG sensor technology is in many aspects technically superior to existing electrical sensors.



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1 ***Spatially and spectrally resolved decoupling of white light by a CSC element in the core of a single-mode optical fiber.***

2 ***FBG readout systems with integrated broadband light source and CSC element.***

FIBER-OPTICAL INTERROGATOR: LIGHT – MEASURE IT

Solution

Fraunhofer HHI developed and patented a point-to-point Fiber Bragg Grating (FBG) writing process using femtosecond laser technology, enabling high-precision direct inscription of different types of Bragg Gratings (standard FBG, apodized FBG, n-shifted FBG, chirped FBG etc.) in almost all fiber types by means of a fully automated process without any pre- or post-treatment of the glass fiber. In addition, Fraunhofer HHI has developed innovative system components based on this technology for fiber-optic sensors and interrogators. These include so called Chirped Scattering Center (CSC) elements, which are inscribed in the core of an optical fiber by applying femtosecond lasers. The effect of the CSC structure is the off-axis dispersion of light guided in the fiber into its spectral colors, Figure 1 shows this effect. CSC elements can be used for building miniaturized fiber-coupled spectrometer devices, which are part of the sensor systems for reading out FBG sensors. Consequently, a completely new, extremely miniaturized and ultra-light FBG sensor system has been developed based on the CSC fiber element.

Realization

The fiber-optical integrated interrogator module based on CSC elements was developed and used as a main system component for a wide variety of applications. Some examples are measuring systems for structural monitoring of critical components, for determining laminar and turbulent wind flows, as a supplement tool to battery management systems or in data gloves as an intuitive human-machine interface. Three scientists, involved in the development of this technology at Fraunhofer HHI founded a spin-off company at the beginning of 2018. They apply licensed CSC structures for fiber-based mini-spectrometers in order to subsequently market them for various applications.

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FIBER-OPTICAL MULTIFUNCTIONAL DATA GLOVE: FIBER – FEEL IT

At a glance

Irreparable nerve damage in the hand area can limit the quality of the life of patients in various ways. For instance, fingers and hands without sensory perception can only be moved precisely if they are within the patient's field of vision. This means that the keyboard of a computer can only be used to a limited extent and it is virtually impossible to grasp objects inside a bag. In Europe alone, the number of patients with nerve damage of this kind is about 600,000 per year.

1 ***Fiber-optic data glove for digitizing both movement and tactile information.***

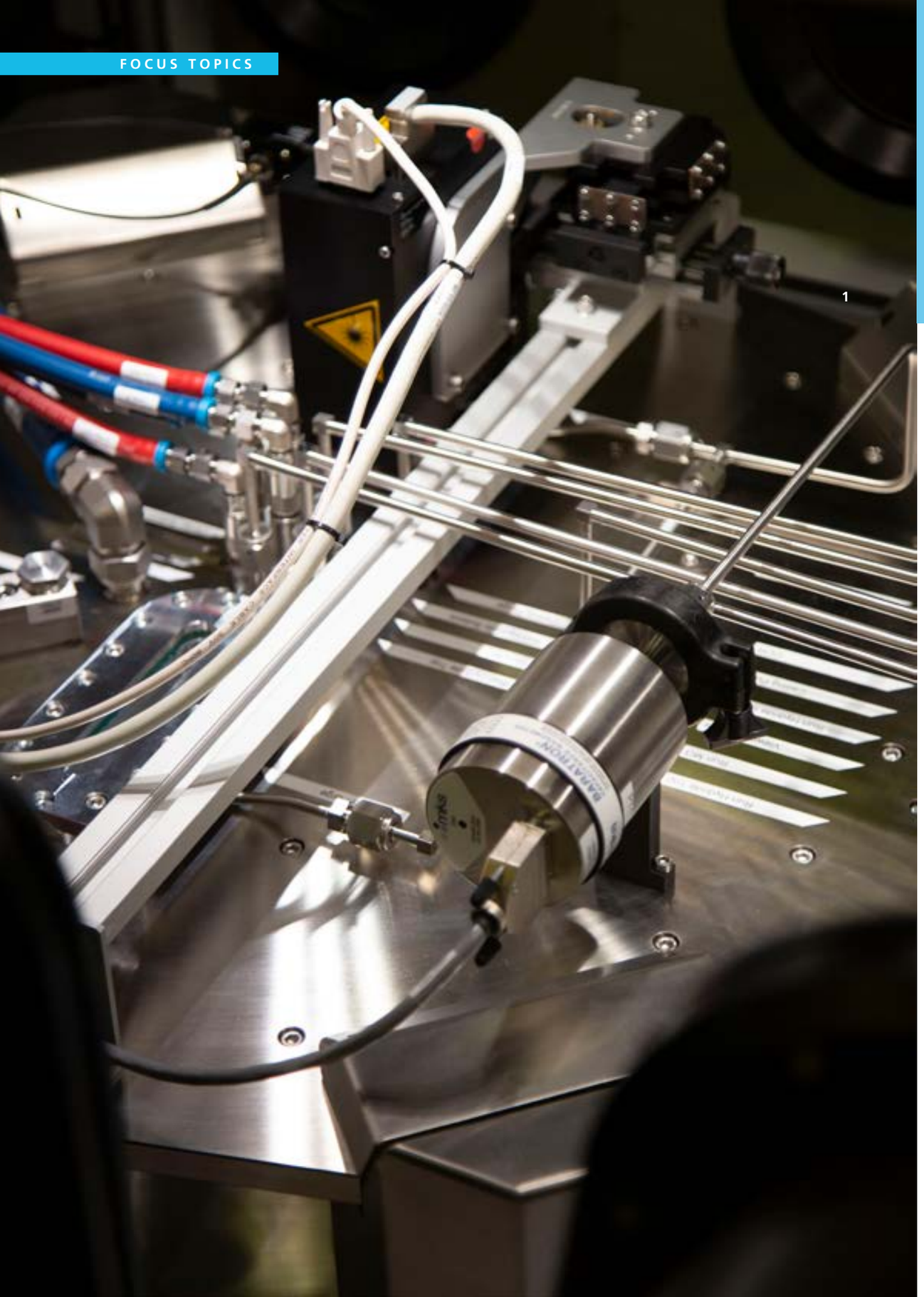
Solution

The goal of this project is to use non-invasive technology in order to restore the sense of touch to patients with sensory loss in one hand. This is achieved by means of two communicating components, a sensor glove and an actuator device integrated in an arm cuff. The glove is equipped with sensors in such a way that both finger and hand movements as well as sensory phenomena - i.e. temperature and contact pressure- are recorded in real time and then transmitted digitally to the actuator component. Based on the FiberLab technology platform developed at Fraunhofer HHI, femtosecond laser technology is used to integrate suitably functionalized optical sensor fibers into a glove. Thus, basic motor and sensory functions such as three-dimensional movements of fingers and the hand as well as temperature and contact pressure can be determined in real time.

The main advantages of this fiber-optic data glove compared to state-of-the-art technology are the degree of miniaturization, the high mechanical flexibility of the glove with its integrated sensors that for the first time allow almost unlimited mobility of the fingers and the hand including a sensory multifunctionality. The operation of the fiber-optic data glove is improved by using a new type of electro-optic transmitter and receiver unit, the interrogator. This interrogator is unprecedented in terms of its degree of miniaturization, weight, performance and full integration into the glove. The entire system control (light source and spectral signal detection) including data evaluation occurs in an integrated microcontroller. The system is battery-operated with a sampling rate of 50 Hz, ensuring real-time data acquisition. The data glove transmits the basic motor and sensory functions of both the hand and the fingers to the actuator device integrated in an arm cuff digitally via Bluetooth or WiFi. This cuff is firmly affixed to the forearm and transmits the digitized and encoded output signals of the multifunctional data glove to intact nerves

Realization

The individual components - the multifunctional fiber-optic sensor glove and the actuator cuff - are already available as functional models. They are going to be adapted and assembled into a functional demonstrator as part of the FMD "Gründermodul" („Founder Module") in a joint project between Fraunhofer HHI and Fraunhofer IZM. Subsequently, the result will be provided to the spin-off team "GHOST - feel it" for commercialization.



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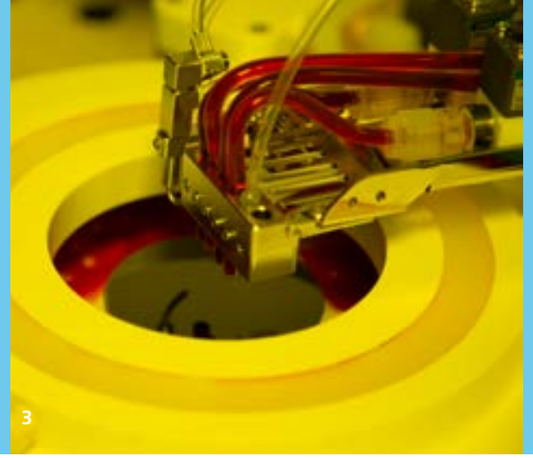

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ENHANCEMENT OF THE InP PROCESS LINE:

Investments from German federal and state governments and the Fraunhofer-Gesellschaft (FhG)

Forschungsfabrik Mikroelektronik Deutschland (Research Fab Microelectronics Germany, FMD).
The InP process line is the technological heart for the development of optoelectronic components at Fraunhofer HHI. From 2016 to 2020, the German federal and state governments, the Fraunhofer-Gesellschaft and Fraunhofer HHI will have invested 30 million euros in the process line, with 16.2 million euros going to enhancements of the line as part of the FMD.

In epitaxy, where production of all components begins, two new crystal growth systems using MBE and MOCVD were purchased. Both systems are capable of growing nanostructures with thicknesses of only a few atomic layers as well as applying innovative dopants.

A primary objective of the process technology investments is achieving a higher level of integration for PICs (Photonic Integrated Circuits). To do so, new light exposure systems were necessary, as were wafer steppers, high-performance Gaussian-beam electron lithography and automatic resist coating and development units. This supports both fine-tuning process precision at several tens of nanometers as well as the reproducibility of the resist structures down to a few molecules. New dry etching methods are used to transfer the structures to the semiconductor and can be exactly controlled using more precise in-situ measurement technologies. A new focused-ion beam unit can now directly analyze the wafers. Modern analyzers support material analysis by SIMS and EDX as well as the creation and evaluation of TEM slices, i.e. slices with a thickness of only a few atomic layers.

The increasingly important integration of InP with silicon can now be carried out using modern bonding technologies at Fraunhofer HHI. In addition, an opto-electrical measurement station for up to 1 Tbps for characterization of the increasingly high-performance products and an automated wafer tester for up to 145 GHz are also available.

The extensive investments will make it possible for Fraunhofer HHI to continue expanding its product portfolio based on InP and to stay at the top of research.

1 *Aixtron G4 reactor with Laytec EpiCurve®TT in-situ measuring head.*

2 *Nikon wafer stepper for lithographic exposure.*

3 *Lacquer head of an automated lacquering and developing unit.*

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PLATFORMS FOR COLLABORATION

TiME Lab – Tomorrow's immersive Media Experience Lab

The term TiME Lab (Tomorrow's immersive Media Experience Laboratory) refers to a whole chain of systems and fields of application that are being researched and developed by the project. The showroom in Berlin combines expertise in 180-degree video projection, spatial audio reproduction and real-time transmission of panorama video. The showroom at Fraunhofer HHI was opened in 2009 to demonstrate these new media capabilities. The TiME Lab is unique in its design. Within a room of 60 m2 equipped with a 3.35 m x 12 m-long curved screen, 14 full HD projectors and a ring of 120 loudspeakers at ear level, 15 ceiling loudspeakers and 4 subwoofers, the TiME Lab sets new standards in the field of immersive media technologies.

The room has acoustics that far exceed those of a conventional cinema. Precise sound reproduction is achieved by elaborate acoustic insulation: speakers are embedded in the insulation material. Audiences receive a directional impression by using four independently controlled subwoofers, even for tones and effects in the low-frequency range.

In addition to its initial application as a research and collaborative platform in the media sector, the TiME Lab is now also used for industrial applications. It has established itself as a platform for realistic audio-visual presentation design concepts, infrastructure and noise-abatement measures in urban planning. It allows an observer to experience the results of even complex noise-abatement measures.

The TiME Lab is a suitable communication tool for a dialogue with decision-makers from business, politics, and society, as well as direct stakeholders.

1 *180-degree panoramic projection in the TiME Lab at Fraunhofer HHI.*

2 *3IT is the home of a wide variety of immersive media technologies.*

3IT – Innovation Center for Immersive Imaging Technologies

The 3IT is simultaneously a network, showroom, test lab, marketing platform, and event location. The aim of the innovation center is to create synergies by building bridges between research and industry. Covering an area of over 600 m2, 3IT is not only a virtual network, but also an exhibition area and venue in the heart of Berlin. It is a place where new products and systems for the industrial, medical, cultural, and entertainment sectors are developed, tested, and presented to various target groups. The current focus is on 3D technologies, VR/AR/XR, volumetric video, UHD, and HDR. The partners of 3IT are offered the unique opportunity to collaborate in developing the field of immersive imaging technologies in a pre-competitive environment. They combine specific competencies from various areas and thus cover the entire sector. Using this extensive pool of expertise, new quality standards are continuously being developed and project ideas realized. Simultaneously, the 3IT offers sufficient space to introduce the acquired knowledge to a professional audience in conferences and workshops and thus facilitate knowledge transfer.

CINIQ Center – Smart Data Forum / Gemeinsam Digital

The CINIQ Center, funded by the Federal Ministry for Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie, BMWi), is a place of technology and information transfer at the intersection of innovation, science, and business in Berlin. CINIQ has served as the home of the Smart Data Forum since 2016, offering an attractive 500 m^2 demonstration and experience space for Smart Data solutions and a place for networking at the European as well as international level.

The Smart Data Forum focuses on Smart Data in promising new applications, unresolved technological challenges, and open social questions. It promotes discourse and exchange among experts and informs the public (including international visitors) about current trends in Smart Data through the use of more than 15 changing demonstrators/prototypes.

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Additionally, it provides information on topics such as Artificial Intelligence and general digital transformation. CINIQ has also been home since early 2018 to the demonstration facility of the federal SME joint program for digitalization "Mittelstand 4.0 Kompetenz-zentrum_Gemeinsam Digital". It offers companies and their employees a contact point for vivid and interactive insights into digital solutions for small- and medium-sized enterprises (SMEs) and shows how successful digitization can be.

For start-ups, SMEs and other interested parties, there are national and international delegations, workshops, project meetings, and recruiting events, as well as annual events. These cover topics such as Artificial Intelligence in healthcare and industry, the digitalization of the chemical industry and secure digital identities using block chain technology. As of December 2018, the number of visitors to the Smart Data Forum since its founding had already exceeded 10,000.

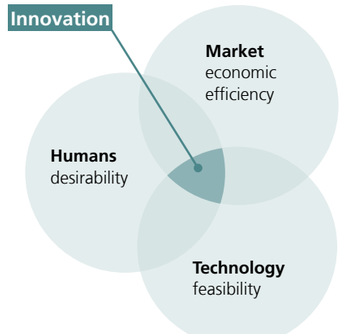
5G BERLIN e. V.

The 5G BERLIN e. V. innovation cluster is a partnership between research and industry for the promotion of innovations related to 5G: the key technology for the communication network of the next generation. The goals of the 5G BERLIN e. V. innovation cluster are to test 5G technologies under real conditions and to promote a wide range of innovative 5G applications.

5G-Center

The 5G Center was founded last year and comprises various regional and international stakeholders from the communications industry, including small and large companies, research institutes, associations and networks. Members and customers connect within the 5G Center. The goal is to promote networking of the traditional telecommunications industry with new 5G stakeholders, including links to the Berlin start-up scene, a major force behind the local economy.

5G Center



SMEs/Start-Ups
· Collaboration partner for 5G applications
· Promotion of the economy

Industry
· Enhancing competitiveness
· Facilitating innovation transfer

Research
· Market proximity
· Networking with industry

Public
· Participation in future oriented issues
· Platform for workshops/discussions

5G Testbed

5G Test Field (5G Testfeld)

The 5G Test Field includes the sustainable development and operation of an efficient test infrastructure on the north campus of Technische Universität Berlin. The users of this experimental environment make an enormous contribution to the economic development of related industries and the city of Berlin by first prototyping their ideas and visions, then testing them until they are ready for the market. To fully exploit the innovation potential, the infrastructure will be upgraded to the current state of the art and be available for a wide variety of 5G applications and user groups. This unique strength of diversity and openness puts the project in a leading European position.

Application cases

The 5G Test Field maps all relevant technology components of a convergent 5G network and promotes the development of innovations in Berlin. This location particularly targets the future-oriented application industries of Augmented and Virtual Reality, intelligent mobility, intelligent supply networks, security applications, and Industry 4.0.

1 *A place for the transfer of technology and information: the CINIQ Center at Fraunhofer HHI.*

2 *The Smart Data Forum educates the public about current Smart Data trends by means of changing demonstrators.*

3 *The members of 5G BERLIN e. V. at the launch of the association in September 2018.*

ORGANIZATIONAL PLAN OF THE FRAUNHOFER HHI

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- **FiberLab** — Dr. rer. nat. Martin Angelmahr
- **Battery Sensor Technology** — Dr.-Ing. Christian Kelb
- **Surface Processing** — apl. Prof. Dr. Eike G. Hübner

Photonic Networks and Systems
Prof. Dr.-Ing. **Ronald Freund**

- **Submarine and Core Systems** — Dr. rer. nat. Colja Schubert
- **Metro, Access and In-house Systems** — PD Dr. rer. nat. Volker Jungnickel
- **Free-Space Optical Systems** — Dr.-Ing. Nicolas Perlot
- **Digital Signal Processing** — Dr.-Ing. Johannes Fischer

Wireless Communications and Networks
Prof. Dr.-Ing. **Slawomir Stanczak**
Dr.-Ing. **Thomas Haustein**

- **System Level Innovations** — Dr.-Ing. Lars Thiele
- **Technologies and Standards** — Dr.-Ing. Thomas Haustein
- **Signal and Information Processing** — Dr.-Ing. Martin Kasparick
- **mm-Wave** — Dr.-Ing. Wilhelm Keusgen

Division Video
Dr.-Ing. **Ralf Schäfer**

Video Coding and Analytics
Dr.-Ing. **Detlev Marpe**
Dr.-Ing. **Thomas Schierl**

- **Multimedia Communications** — Dr.-Ing. Thomas Schierl, Dr.-Ing. Cornelius Hellge
- **Image and Video Coding** — Dr.-Ing. Detlev Marpe, Prof. Dr.-Ing. Heiko Schwarz
- **Embedded Systems** — Prof. Dr.-Ing. Benno Stabernack
- **Machine Learning** — Dr. rer. nat. Wojciech Samek
- **Image and Video Understanding** — Dr.-Ing. Karsten Müller, Dipl.-Ing. Thomas Meiers

Vision and Imaging Technologies
Prof. Dr.-Ing. **Peter Eisert**
Dipl.-Ing. **Peter Kauff**

- **Computer Vision and Graphics** — Prof. Dr.-Ing. Peter Eisert, Dr.-Ing. Anna Hilsmann
- **Immersive Media and Communication** — Dipl.-Ing. Ingo Feldmann, PD Dr.-Ing. Oliver Schreer
- **Capture and Display Systems** — Dipl.-Ing. Peter Kauff, Dipl.-Ing. Christian Weißig

Quality Management and Safety
Dipl.-Ing. (FH) **Mario Perkowski**

Administration
Dipl.-Betriebsw. (FH) **Silvia Korn**

Corporate Communications
Dipl.-Kffr. **Kathleen Schröter**

PHOTONIC NETWORKS AND SYSTEMS

The department of Photonic Networks and Systems develops high-performance optical transmission systems for the use in access, in-house, metro, wide-area and satellite communication networks. The research work focuses on increasing the capacity as well as improving safety and energy efficiency. The department is equipped with the latest technology, excellent system laboratories, efficient simulation tools and the means to carry out field tests.

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PHOTONIC NETWORKS AND SYSTEMS

Elastic optical networks with scalable capacity and low latency

Network operators increasingly have to invest in the flexibility and scalability of their networks. Until now, oversized transmission capacities in the networks have been allocated without taking into account the actual capacity demand per transmission link. Evolving the network-dimensioning paradigm towards demand-oriented allocation of bandwidth resources in the optical layer, contributes to more efficient use of existing fiber infrastructure by utilizing capacity reserves. The objectives of current research are software-configurable, optical transmission systems characterized by flexible data rates that can provide transmission capacities per channel up to the Terabit/s range with fine granularity. Applications can be found in both core and metro networks. A further challenge is the efficient integration of distributed computing and storage units and what are referred to as "edge clouds" in order to be able to provide, e.g., low-latency for future 5G services.

Terabit/s satellite communication and secure Quantum Key Distribution

Future telecommunication satellites in geostationary orbit will be dimensioned for Terabit/s throughput due to the increasing demand for bandwidth. To meet this demand, Fraunhofer HHI is developing free-space optical solutions that meet the strict requirements for antenna gain (beam divergence in the 10-µrad range). The required data rates in the Terabit/s range are achieved using wavelength division multiplexing (WDM) technology in the 1550 nm transmission window of the atmosphere. The prototypes designed for the European Space Agency (ESA) feature techniques against atmospheric turbulence to deliver a robust bidirectional transmission between ground station and satellite. The space-based optical transmission systems that have been developed are also used for research on secure Quantum Key Distribution systems.

High-speed wireless transmission with high carrier frequencies

Interest in terahertz (THz) transmission as a supplement both to existing wireless transmission technologies and those being developed has grown considerably in recent years. High carrier frequencies in the low-THz range (0.1-2.0 THz) are used in THz transmission. This facilitates wireless transmission at data rates in the 100 Gigabit/s range over short-to-medium distances (1km) – a transmission capacity previously achieved only in optical-fibers – making wireless extension and bridging of fiber-optic connections feasible. Other fields of application include backhaul and fronthaul scenarios in next-generation mobile networks.

Data transmission with visible light

Optical wireless data communication is an attractive solution for areas with special security and electromagnetic compatibility requirements. Fraunhofer HHI has developed a transmission technology that enables commercially available LED lamps used for room lighting to transmit data wirelessly. Using this technology, data rates of 1.6 Gigabit/s per wavelength can already be achieved today. Current work includes experiments in different application scenarios in addition to the development of advanced communication protocols to extend the network functionality for mobile users.

Hybrid access network planning

Fiber-optic technology is particularly sustainable in achieving high data rates in the access network. However, the expansion of a fiber-optic network is associated with high costs, especially for civil engineering. Hybrid access networks significantly reduce deployment costs in the last step by additionally including wireless communication technologies - such as WiFi, 4G/5G and free-space optical communications. Fraunhofer HHI and its partners develop algorithms to plan and cost-optimize hybrid access networks and use them in broadband deployment projects in Germany.

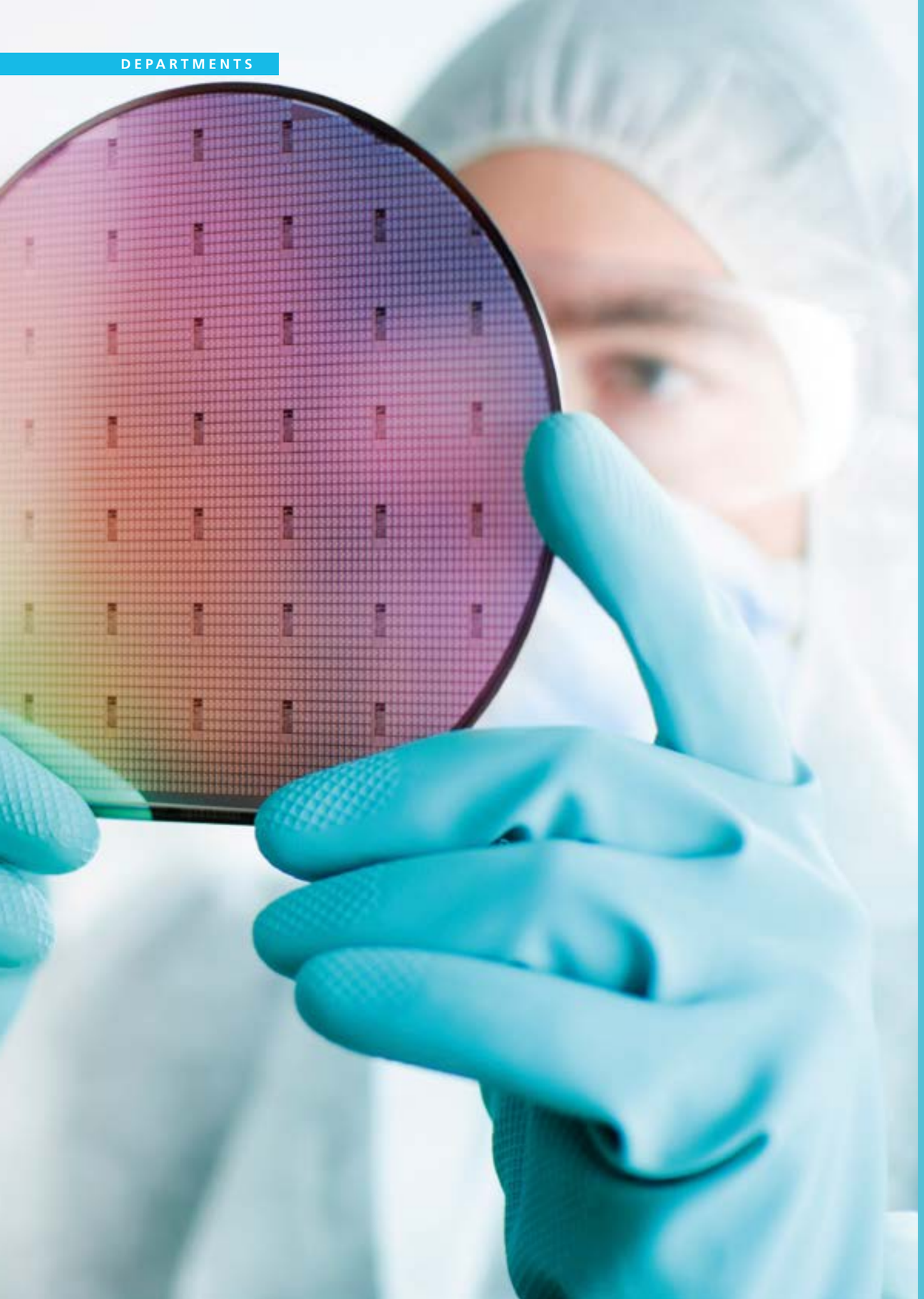
RESEARCH AND DEVELOPMENT

- Elastic optical networks with scalable capacitance and low latency
- Terabit/s satellite communication and secure Quantum Key Distribution
- High-speed wireless transmission with high carrier frequencies
- Planning of cost-efficient, hybrid access networks
- Networked data transmission with visible light

1 *System laboratory for the examination of optical networks.*

2 *Platform for rapid prototyping of optical transmission systems.*

3 *Terminals for data transmission with visible light.*



PHOTONIC COMPONENTS

The amount of data transmitted over the Internet doubles approximately every two years. Through intensive research and development, the Photonic Components department has helped to keep the Internet operating. Currently, every second bit on the Internet touches technology from Fraunhofer HHI on its way from or to the user. In addition to the research and development of optoelectronic semiconductor components for data transmission, integrated optical circuits are being developed. Moreover, the Berlin scientists are researching technologically related fields such as infrared sensors, terahertz spectroscopy, and high-power semiconductor lasers for industrial and medical applications.

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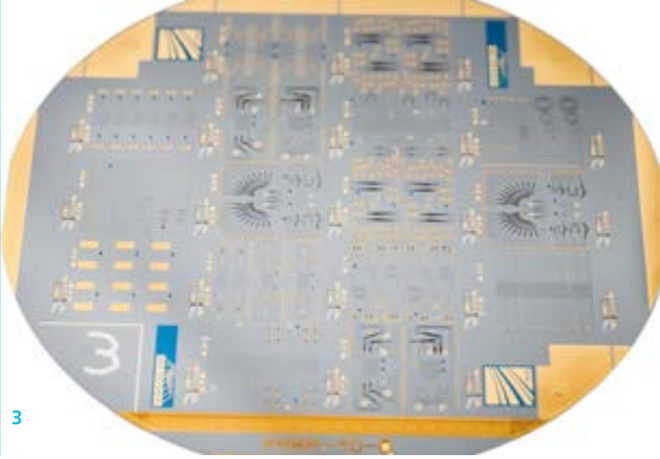

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PHOTONIC COMPONENTS

Indium phosphide (InP) multi-wavelength light source

The next generation of photonic networks requires efficient and densely packed wavelength channels in order to accommodate the further increase in data to be transported in the future. Here, a major challenge is the realization of a cost-effective multi-wavelength laser source. For this purpose, Fraunhofer HHI developed and manufactured InAs Quantum-Dot (QD)-based mode-locked-Lasers (MLL). With a low-cost QD-MLL component such as this, up to 40 wavelength channels can be generated simultaneously with a given mode spacing, whereas otherwise 40 different distributed-feedback lasers (DFB) would have to be used and controlled with regard to their wavelengths.

100 GHz photodetector modules as test equipment for the development of future optical networks

The next generation of photonic networks requires faster components to efficiently accommodate the further increase in data. The simplest approach for faster and cost-efficient data transmission is to increase the baud rate per channel. As a result, fewer components are required for the same amount of data, reducing energy consumption and costs. Electro-optical and optoelectronic components with bandwidth greater than current baud rates are required in test and measurement equipment for the development of future optical transmission paths. Fraunhofer HHI's InP-based technology is particularly well suited for such applications due to its excellent high-frequency properties. Well-known manufacturers of measurement equipment and research institutes all over the world are currently using prototypes of the 100 GHz photodetector modules developed at Fraunhofer HHI.

InP modulators: 300 Gbit/s via high-speed amplitude modulation on a single wavelength channel

The increase in intra- and inter-datacenter traffic demands increasingly faster optical communication connections. Yet the optoelectronic components should combine many functions on one chip, be small and consume little power. On the transmitting side, Fraunhofer HHI is developing highly efficient, superfast modulators based on indium phosphide that meet these requirements. All modulators share very low switching voltages and small chip sizes. A laser source or optical amplifiers can be optionally integrated. It was possible to demonstrate modulator with an integrated laser for the first time with amplitude modulation of 300 Gbit/s on a single-wavelength channel at a clock rate of 100 Gbaud.

PolyPhotonics Berlin, growth core of the BMBF Innovation Initiative "Unternehmen Region" (Enterprise Region)

The technology platform PolyBoard, part of the growth core of "PolyPhotonics Berlin", provides a hybrid-optical construction kit for integrating basic optical elements into complex, modular, flexible and extremely compact functional components. At the heart of this platform is a chip with polymer waveguides that can accommodate additional passive elements such as glass fibers, thin-film optical filters, micro-optics and active components such as photodiodes and laser chips. Connection of these additional elements to the waveguide chip is done with efficient automated-assembly technology. The network of eleven regional companies and three research institutes develops demonstrators for three different fields of application: Cost-effective transceiver chips and passive multiplexers for the telecom/datacom market, tunable laser sources at 1064 nm and 785 nm for the analytical industry, and miniaturized interrogators for fiber-optic sensors. The project partners founded the PolyPhotonics Berlin association (e. V.) to jointly market the project results.

RESEARCH AND DEVELOPMENT

- Indium phosphide (InP) multi-wavelength light source
- 100 GHz photodetector modules for test equipment necessary to the development of future optical networks
- InP modulators: 300 Gbit/s via high-speed amplitude modulation on a single wavelength channel
- PolyPhotonics Berlin, growth core of the BMBF Innovation Initiative "Unternehmen Region" (Enterprise Region)

1 *Wafer processing at Fraunhofer HHI.*

2 *Photodetector module with 100 GHz bandwidth.*

3 *Multi project wafer as a service for approximately 50 external partners.*

FIBER OPTICAL SENSOR SYSTEMS

The Fiber Optical Sensor Systems department is working on a new generation of photonic sensors designed for use in measurement and control systems. These systems are used for early hazard detection, energy management, robotics in industrial and medical applications. The sensors are characterized by extreme miniaturization, high network and communication capability as well as high energy efficiency. Femtosecond laser material processing technology is used for manufacturing tailored optical sensors for specific applications, integrating optics

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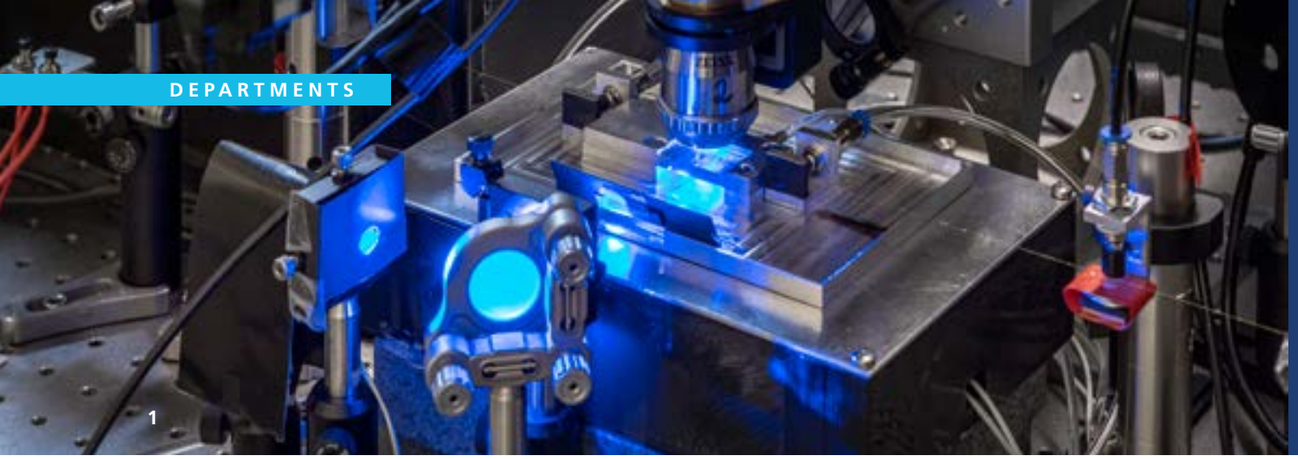

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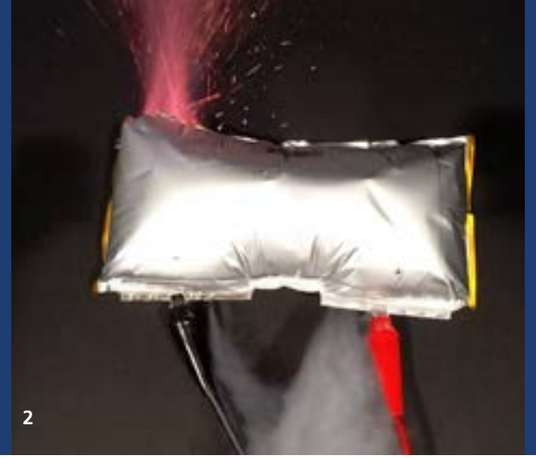

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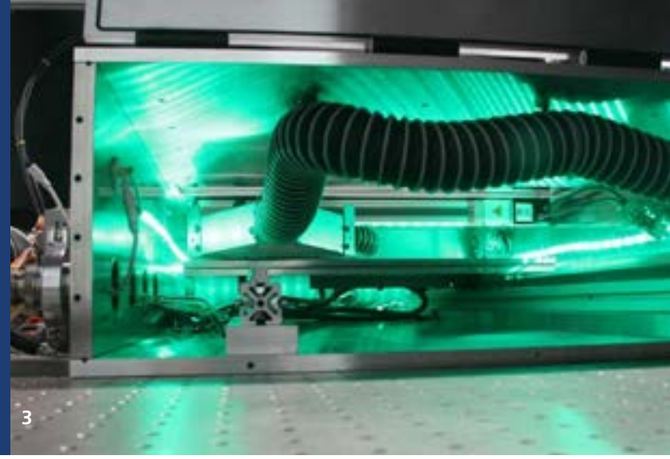

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FIBER OPTICAL SENSOR SYSTEMS

FiberLab technology platform

FiberLab is a highly flexible and efficient fiber optical technology platform developed by the Fraunhofer HHI using femtosecond laser technology. It evolved as part of a large number of different research and development projects. FiberLab is subdivided into three sections: FiberNavi, FiberChem and FiberSens and supports applications such as 3D ShapeSensing, Cyberglove and FOMACS (Fiber optical measurement and control system).

3D ShapeSensing: Researchers at the Fraunhofer HHI located in Goslar developed the world's thinnest fiber optical 3D shape sensor using a standard single-mode fiber for reconstruction of a 3D profile. These sensors are used in the oil and gas sector as well as in a variety of industrial applications, in medical technology and in the maritime sector. Moreover, these 3D shape sensing sensors can be combined with other customer-specific multifunctional sensors, produced by Fraunhofer HHI, like fiber optical sensors for pressure, temperature and strain.

Cyberglove: The department has developed a fiber-optic glove as an innovative human-machine interface for virtual control of robots or high-accuracy motion detection. To preserve users' complete freedom of movement, the data is transferred with low-latency WiFi to a superordinate system.

FOMACS: The mobile, miniaturized fiber optical readout system FOMACS enables the precise acquisition and evaluation of fiber optical sensor signals. This data can also be broadcast in a customer-specific format to a superordinate system.

Material processing and packaging with ultra-short-pulse technology

Ultra-short-pulse laser technology is used to functionalize the surfaces of a wide variety of materials so that they are more suitable for battery electrodes, for example, or for generating hydrogen with excess electrical energy of wind power plants for energy storage. Moreover, they can be used for many other applications, from improved passive cooling of electronic components to texturing of PMMA plates for innovative LED lighting. Fraunhofer HHI has a production facility for large-scale material processing at its disposal for these purposes.

Battery and sensor technology test center

A battery and sensor test center was opened at the Fraunhofer HHI site in Goslar in 2015. It develops and tests new and innovative concepts for enhanced battery safety. The focus is on lithium-ion storage systems. These are tested under extreme conditions using both active and passive battery safety systems. In addition to individual battery cells, entire battery-based storage systems are being investigated for both stationary and mobile applications. Besides two fire-test furnaces, a climate container and several battery test stands with up to 1.2 MW loads are available for this purpose. This enables battery tests to be carried out not just over their normal operating range, but to complete incineration including gas analysis.

RESEARCH AND DEVELOPMENT

- Fiber optical microsensors (FiberLab)
- Material processing and packaging using ultra-short pulse laser technology
- Advanced battery-safety technology

1 *Manufacture of fiber optical sensors using ultra-short pulse lasers.*

2 *Abuse test of a lithium-ion battery.*

3 *Surface functionalization using high-repetition-rate* ultra-short pulse lasers.

WIRELESS COMMUNICATIONS AND NETWORKS

The Wireless Communications and Networks department conducts research in the field of wireless data transmission. The researchers make extensive contributions to the theory, concept development, technical feasibility and standardization of wireless systems. This is achieved in close cooperation with numerous companies and organizations. The department's range of services is rounded out by scientific studies, simulations and evaluations at the link and system level, field measurements, as well as the development and construction of hardware prototypes.

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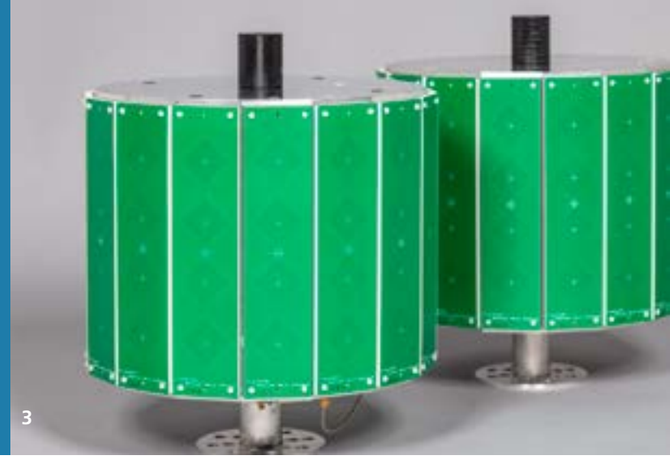

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WIRELESS COMMUNICATIONS AND NETWORKS

Research for the future of mobile data transmission

Wireless communication has become an indispensable part of professional and private life. The Wireless Communications and Networks department is conducting research into future trends in this area in order to provide adequate technical solutions. The enormous and constantly increasing demands placed on data rates, security, robustness and latency have to be considered, while access to different and often widely distributed data sources needs to be provided. To help accomplish this, the department works together with national and international partners from government, industry and academia to set the course for fifth-generation (5G) mobile networks. 5G application cases were defined and their solutions developed during the previous reporting period. This was achieved, among others, in several projects under the 5G PPP (5G Infrastructure Public Private Partnership) program for increasing the 5G competitiveness of the European telecom industry.

The 5G PPP projects continued during the current reporting period and were mostly completed. The frequency range from below 6 GHz up to 100 GHz was examined for its suitability for 5G, several channel measurements were performed and demonstrators were set up and tested extensively for validation. Many of the results have been submitted to 3GPP (3rd Generation Partnership Project), the 5G standardization organization, and ITU, the specialized UN organization responsible for global radio communications.

In addition, research is being carried out on the extension of 5G. For instance, Machine Learning algorithms were used in low-mobility scenarios to detect more input signals than antenna elements on the receiver.

Autonomous vehicle communication for off-road applications

The operation of agricultural and construction machinery increasingly resembles complex manufacturing processes in the industry. The requirements for efficiency, precision and safety are correspondingly high. Automated - and in the end completely autonomous - operation improves these processes.

In order to achieve this goal, scientists have researched a mobile and infrastructure-less 5G networking solution that meets the requirements of tactile communication – for which low latency in particular is crucial. The innovative communication system is intended to be integrated smoothly into existing mobile networks and is thus a dynamic and demand-oriented extension of the 5G network. Additionally, an integrated high-precision localization solution is being developed. This solution takes into account the special requirements of the agricultural and construction industries.

Massive MIMO for 5G applications: from theory to practice

Massive MIMO systems consist of a large number of antenna elements. They enable a targeted supply of the respective mobile phone users via so-called beam forming - the emission of designated, narrow transmission lobes. This technology is essential to achieve very high transmission rates in 5G.

As part of a 5G research project, the department has developed a flexible, scalable, reciprocal Massive MIMO system consisting currently of 32 active single antennas. The efficiency of each individual antenna module is considerably increased by a digital linearization stage. Moreover, a newly developed calibration method improves the angular accuracy of signals received. The method is used to increase the reception capability and to localize the user. Simple integration into existing base stations is achieved via two standardized interfaces.

RESEARCH AND DEVELOPMENT

- Fifth-generation mobile networks (5G)
- Reliable industrial communication with low latency
- Vehicle-to-vehicle communication
- Multi-antenna systems (MIMO, Massive MIMO)
- Communication with millimeter-wave technologies
- Cognitive radio systems and networks
- Software Defined Radio (SDR)
- Machine Learning for mobile networks

1 *Robust micro-drone control via the Fraunhofer HHI-3G speech channel module.*

2 *Open development platform for vehicle-to-vehicle communication.*

3 *128-port measuring antennas for direction-resolved channel measurements at 3.5 GHz carrier frequency.*

VISION AND IMAGING TECHNOLOGIES

The Vision and Imaging Technologies department researches on cutting-edge technologies for the entire video processing chain, from content creation and editing to final rendering. Special emphasis is placed on advanced 2D/3D analysis and synthesis methods in multimedia, medical and industrial applications. These require development of sophisticated solutions for immersive and interactive systems with innovative camera, sensor, display and projection technologies.

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VISION AND IMAGING TECHNOLOGIES

Video analysis and human machine interaction in medical and industrial applications

Several multi-modal image analysis methods have been developed in order to improve the working environment of physicians in critical settings, such as during surgery or in intensive care units, by presenting relevant information intuitively and rapidly. A 3D video analysis method enables the extraction of depth information during surgical procedures as well as the measurement of 3D structures. Similarly, multi-spectral imaging also allows greater in-depth analyses of tissue properties as well as the capture of vital-sign data. Touchless operation for user-adaptive image visualization makes it possible to comprehensively visualize data without impact on clinical hygiene. Touchless interaction can also be successfully used in industrial contexts for human-robot interaction and process monitoring.

High-resolution video panoramas for cultural and industrial applications

High-quality 360-degree UHD video panoramas with a resolution of up to 20K are continuously increasing in importance for a wide variety of applications. They can be viewed with high-resolution VR glasses as well as on large screens with complex multi-projection systems or LED panels. Fraunhofer HHI has developed the OmniCam-360 in order to generate content for 360-degree video production. It consists of a special mirror system with ten HD cameras or in an additional configuration level with ten 4K cameras. Their individual images can be seamlessly combined in real time to form a 360-degree UHD video panorama. This makes it possible to interactively experience live events using tablets, smartphones and VR glasses. The viewer feels immersed – directly transported into the action. After appropriate post-production, the video panoramas are also suitable for projections in walk-through 360-degree rotundas.

German rail-service provider Deutsche Bahn uses this technology to demonstrate noise abatement measures. Here, passing trains are recorded using special 3D sound systems and are realistically presented at what is called the "Infopunkt Lärmschutz" (Noise Simulation Laboratory). In addition, recordings of a number of cultural and public events (concerts, sports, etc.) have been successfully produced using this technology.

3D reconstruction of persons, objects and environments for VR applications

New media formats such as walk-through films using VR, AR and MR require innovative algorithmic solutions from the field of Computer Vision. The objective of the Institute in this area is to create highly realistic and complete 3D reconstructions of moving persons. To do so, it has combined Computer Vision and Computer Graphics to develop new techniques for graphically representing persons by high-quality, photo-realistic models that can be integrated in virtual or real scenes. Modifications are possible here as well, for example changing perspective, establishing eye contact or editing and correcting movements. 3D Human Body Reconstruction (3DHBR) technology was put into commercial operation in June 2018 at the spin-off Volucap GmbH together with partners ARRI, UFA, Studio Babelsberg and Interlake in a specially developed 360-degree recording studio.

Reliable authentication of persons in security applications

Secure, automated verification of a person's identity is becoming increasingly important, for example at ABC gates at airports, for access control systems, mobile applications in e-commerce and in the financial sector. Here, the human face plays an important role as a simple, accepted biometric feature for touchless identification through facial-recognition systems.

Attacks against such systems have emerged in the past, for example substitution of manipulated reference imaging (face morphing attacks) or counterfeiting other identities using pictures, masks or models (presentation attacks), all of which constitute a threat to automated identity checks. To counter this, innovative and robust image analysis methods based on Machine Learning are being developed to detect manipulations made to facial images as well as the appearance of the face itself. The procedures also support reliable and secure authentication of persons.

RESEARCH AND DEVELOPMENT

- 2D and 3D image and video processing
- 3D capture and rendering
- Highest-resolution audio-visual immersive systems
- Human-machine interaction and Augmented Reality
- Applications: multimedia, medicine, industry, and security

1 *High-resolution 360-degree video panoramas with the OmniCam-360.*

2 *Interactive VR and AR applications.*

3 *Touchless interaction for remote collaboration.*

VIDEO CODING AND ANALYTICS

The global growth rates of all types of Internet-based video data are continuously increasing. Currently, the data volume for Internet video is predicted to triple by 2022. As a result, the share of IP-based video in global data traffic is expected to rise to over 80 percent by then. Additionally, the proportion of 4K television sets in households is expected to increase to almost two thirds. Thus, the efficient coding, transport, processing and analysis of increasingly high-resolution video signals are becoming even more important. The department covers all relevant aspects of the related research areas. In the past, it has made significant contributions to the H.264/MPEG-AVC and H.265/MPEG-HEVC international video coding standards, helping to provide the key technologies for the increasing adoption of digital video in everyday life.

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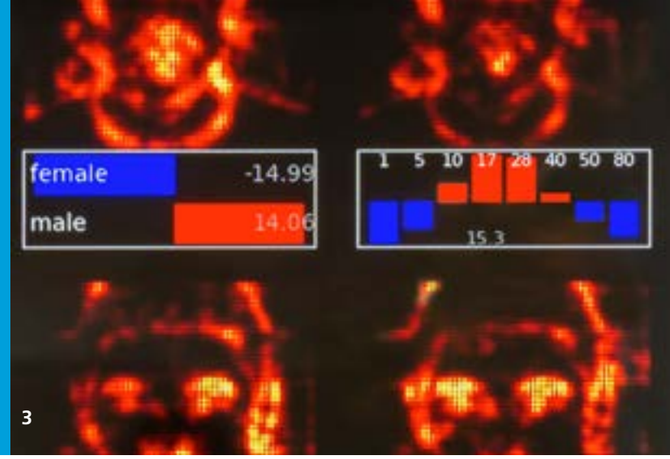

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VIDEO CODING AND ANALYTICS

Contributions to video coding standards and related implementations

While H.264/MPEG-AVC is the most widely used video encoding standard worldwide, its successor H.265/MPEG-HEVC (High Efficiency Video Coding) is now being introduced on almost every mobile end-user device and television set. Fraunhofer HHI was actively involved in the development of both standards. A HEVC real-time encoder was developed in the department. It is based on the experience gained from standardization and is now being successfully marketed by a German industrial partner. It is currently used, for example, in commercial 4K/UHD live soccer transmissions and in the transmission of television programs in HD quality via DVB-T2.

As efficient as the current standards are, the growth rates of compressed video data demand compression that is even more efficient. To meet this challenge, the ITU Video Coding Expert Group (VCEG) and the ISO/IEC Moving Pictures Expert Group (MPEG) have already started working together on a new standard in the Joint Video Experts Team (JVET). The standardization of Versatile Video Coding (VVC), the successor to HEVC, started in 2018. Fraunhofer HHI's proposal not only included subsequent further development of already existing technologies, but also new compression methods that, for example, were developed with the help of Machine Learning. This proposal achieved a bit-rate reduction of up to 40 percent compared to HEVC at the same image quality. The Fraunhofer HHI proposal was thus among the best in all three categories tested (standard, high dynamic range and 360-degree video).

Machine Learning

The reverse navigation of deep neural networks to explain classification results is one of the areas investigated in the basic research on Machine Learning at Fraunhofer HHI. This technique allows determining the point at which a certain group of neurons made a certain decision and how much this decision contributed to the result. This information can be used for validation purposes by an expert (such as in medical applications), or to improve the AI algorithm. Additionally, methods to quantify uncertainty in Machine Learning are being developed. The knowledge whether or not the algorithm was confident in a decision is of great importance for practical applications and promotes general confidence in the AI system. Both topics - transparency of decisions and knowledge about uncertainty - are particularly important for applications in medicine. Thus, Fraunhofer HHI is investigating them in the standardization activities of the ITU/WHO focus group "AI for Health" (FG-AI4H).

A standard for high-quality 360-degree video

VR glasses are creating a new device category for immersive experiences. They will depend on corresponding video content with panoramic views being transmitted to the end-user device via the Internet in a resource-effective manner. Introduced in 2017, the MPEG-OMAF standard provides a significant increase in the quality of 360-degree video for VR. Fraunhofer HHI played a leading role in its development. By combining it with HEVC, high-resolution 360-degree videos can be transmitted to mobile devices. The video is divided into individual tiles. Each tile is then encoded in its original resolution and in a reduced resolution. The receiver selects the tiles depending on the field of vision in such a way that the high-resolution tiles are transmitted to the field of vision of the user while the low-resolution tiles are transmitted for areas outside it. At the end device, such as VR glasses or a TV set, the incoming tiles are combined into a HEVC-compatible video stream and can be decoded with any 4K-capable HEVC decoder. The MPEG-OMAF standard also serves as the basis for the 2018 specification for upcoming VR services in 5G networks.

RESEARCH AND DEVELOPMENT

- Image and Video Coding
- Multimedia Communication
- Embedded Systems
- Machine Learning
- Semantic Analysis of Image and Video Data

1 *Cubemap projection of a 360-degree video with division into a total of 24 tiles.*

2 *EEG-based image quality analysis.*

3 *An example of the reversal of Deep Neural Networks to explain classification results.*

CERTIFICATE

Kiwa International Cert GmbH
certifies that

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Heinrich Hertz Institute
Einsteinufer 37
10587 Berlin

with the location

Fraunhofer Institute for Telecommunications
Heinrich Hertz Institute, Department Fiber Optical Sensor Systems
Am Stollen 19B
38640 Goslar

for the scope

Research, development and production in the fields of photonics and electronics

has implemented and applies a Quality Management System, which is in compliance with the requirements of

ISO 9001:2015

Kiwa International Cert GmbH
Managing Director

Kiwa International Cert GmbH
Technical Manager

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WORKING AT THE FRAUNHOFER HHI

In addition to excellent working conditions and modern laboratory equipment, Fraunhofer HHI offers a variety of career opportunities, especially in the fields of natural and technical sciences, computer sciences, as well as economics and business administration. The Institute partners with industry to jointly develop effective, state-of-the-art, trend-setting. The Institute offers numerous opportunities for secondary school graduates, university students and graduates and young professionals to gain insights into working life and to embark on their careers.

In addition to offering opportunities for student jobs, internships, bachelor and master's theses, and postgraduate programs, Fraunhofer HHI offers apprenticeship positions:

- Office Manager
- IT Specialist
- Microtechnologist

Opportunities for further education

Every employee at Fraunhofer HHI has the opportunity to enhance their professional knowledge and skills. Fraunhofer HHI offers numerous continuing-education programs aligned with various career stages and key activities.

Attractive working conditions

The working environment at Fraunhofer HHI is characterized by a well-equipped workplace with modern laboratory equipment, exciting projects, and a high degree of personal autonomy. Flexible working hours and a parent-child workspace support the compatibility of family and career. Fraunhofer HHI organizes athletic events several times a year for employees during which colleagues from different departments get to know each other. Health services such as yoga classes, screening tests, massage appointments and much more, are offered.

Promotion of young talent

Fraunhofer HHI is conducting research today for the digital infrastructure of tomorrow. The promotion of young scientific talent and equal opportunities for all is a fundamental component of our human resources strategy. Fraunhofer HHI takes part in the nationwide annual Girls'Day, inviting female students to the Institute and offering practical insights into the working world. Independent experiments in the laboratory and various workshops are intended to familiarize female students with STEM careers.

Fraunhofer HHI has worked together with Albrecht Dürer High School in the Neukölln district of Berlin since September 2015. Students there have had the opportunity to independently explore the diversity of career opportunities in application-oriented research through visits and internships to supplement the curriculum with practical experience. This gives the students a perspective on technology and natural sciences beyond the context of traditional STEM education.

Quality management

Fraunhofer HHI has established and implemented a quality-management system in accordance with DIN EN ISO 9001:2015 for the areas of research, development, and production in the field of photonics and electronics for all corporate functions at its Berlin site, Einsteinufer 37. Compliance with standard's requirements was determined by a quality audit.

DID YOU KNOW THAT...

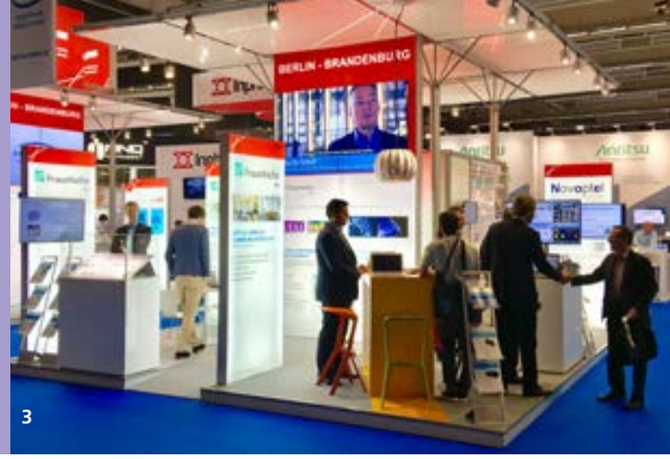
- the Heinrich Hertz Institute celebrated its 90th anniversary in 2018?
- famous entrepreneur Fritz Sennheiser wrote his thesis at the Heinrich Hertz Institute in 1936?
- Fraunhofer HHI maintains a full-service semiconductor fabrication plant in Berlin, in which several of the world's fastest optoelectronic components for data transmission are constructed, such as photodetectors, lasers, and modulators?
- researchers from Fraunhofer HHI, as part of the international expert groups for standards in video compression (VCEG and MPEG), have won the Technology & Engineering Emmy four times?
- the current world standard for motion picture transmission – the video coding standard H.264/MPEG-4 AVC (for HD) and H.265/MPEG-H HEVC (for UHD) – was co-developed at Fraunhofer HHI?
- the first live 3D concert was made possible with the STAN camera assistance system developed at the Fraunhofer HHI?
- researchers of Fraunhofer HHI have developed a method with which data can be transmitted using standard LED lights that reach transmission speeds of over 1 Gbps?
- thanks to the OmniCam-360, you can experience the 2014 World Cup soccer final in a 180-degree UHD panorama video at the FIFA museum and see the Berlin Philharmonic Orchestra in concert through Virtual Reality glasses in a 360-degree view?
- a majority of the quality-management processes of Fraunhofer HHI are certified in accordance with DIN ISO 9001:2015?
- the prototype of the first volumetric video studio on the European continent is located at Fraunhofer HHI?
- 5G technology, the next generation of the mobile radio network, has been researched by Fraunhofer HHI scientists since 2012?

1 *Certification of the Fraunhofer HHI quality-management processes according to DIN ISO 9001:2015.*

2 *The first commercially operated volumetric video capturing studio on the European mainland opened in summer 2018 with technologies from Fraunhofer HHI.*

1

2



3

MEET US
AT TRADE FAIRS AND EVENTS

The experts from Fraunhofer HHI on tour
Our scientists are year-round at various trade fairs and events worldwide. They present the latest results and prototypes of research and development at Fraunhofer HHI. We are regularly attending the following trade fairs:

- SPIE Photonics West
- GSMA Mobile World Congress
- Embedded World Exhibition & Conference
- Optical Fiber Communication Conference and Exhibition (OFC)
- Fiber Optics Expo (FOE)
- Optics & Photonics International Exhibition (OPIE)
- National Association of Broadcasters Show (NAB Show)
- LASER World of PHOTONICS
- Hannover Messe
- CeBIT
- Internationale Funkausstellung (IFA)
- International Broadcasting Convention (IBC)
- European Conference on Optical Communication (ECOC)
- Consumer Electronics Show (CES)

In addition, we have been present at the following exhibitions and events:

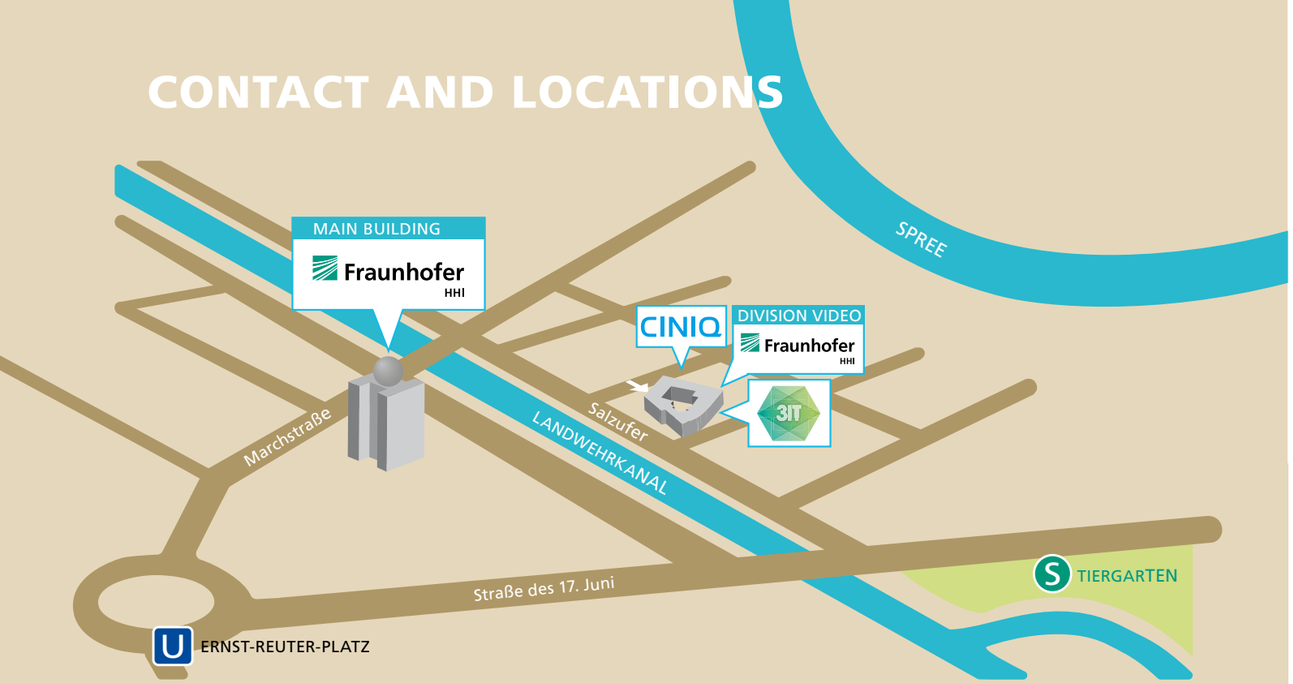
- ITG-Fachkonferenz
- Lange Nacht der Wissenschaften (LNDW)
- PolyPhotonics Berlin
- re:publica
- 3IT Summit
- Science Campus of the Fraunhofer-Gesellschaft
- SIBB Forum Digitale Transformation
- Technology Innovation Days
- Girls'Day

1 *CeBIT 2018*

2 *NAB Show 2018*

3 *ECOC 2017*

CONTACT AND LOCATIONS



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