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FRAUNHOFER INSTITUTE FOR HIGH FREQUENCY PHYSICS AND RADAR TECHNIQUES FHR

ANNUAL REPORT 2019

The future multichannel radar target simulator ATRIUM will make it possible to test radar sensors installed in vehicles in highly complex scenarios.

ANNUAL REPORT 2019

PREFACE

Dear Friends and Partners of Fraunhofer FHR,
Dear Readers,

2019 was a year to celebrate for our institute: The Fraunhofer-Gesellschaft celebrated its 70th anniversary, Fraunhofer FHR its 10th and the Cognitive Radar Department its 5th. These three anniversaries are backed by true success stories, which we celebrated in style together with our guests from the fields of science, defense, business and politics at our 9th Wachtberg-Forum (see page 11).

Another highlight in our calendar featured the Inspector General of the Federal Armed Forces visiting our campus for the first time ever. On July 5, we had the honor of presenting the institute as well the capabilities of our TIRA and GESTRA space radar systems to General Eberhard Zorn (see page 8).

We also have news to report on an organizational level. On June 1, 2019, Dr. Christine Mauelshagen became the Head of the newly created staff unit Strategy and Organizational Development. Continuous strategic work is becoming increasingly relevant in view of our strong growth and Dr. Mauelshagen supports the institute management in these important matters.

On October 19, Fraunhofer FHR collaborated in the commemoration of an event that made history not only for the world of radar. The Institute of Electrical and Electronic Engineers (IEEE), the world's largest professional association of engineers, honored the work of the radar pioneer Christian Hülsmeyer as an IEEE Milestone. A commemorative plaque was unveiled after a ceremony with Cologne's mayor Henriette Reker (see page 6) at Cologne's Hohenzollern Bridge, where Hülsmeyer first presented his »Telemobiloskop« in 1904.

Our top-notch research achievements once again received international recognition last year. We are excited about the NATO SET Early Career Award for Prof. Dr. Daniel O'Hagan and the IEEE Dennis J. Picard Medal for Radar Technologies and Applications for our former colleague Richard Klemm. The research by two of Prof. Knott's students at RWTH Aachen was also honored: Giovanni D'Apice received the AFCEA Student Award 2019 and Jannik Springer the ARGUS Award 2019. In addition, the colleagues Andrej Konforta, Dr. Christos Liontas, and Dr. Thomas Bertuch received the 2019 IEEE Antennas and Propagation Ulrich L. Rohde Innovative Conference Paper Award on Antenna Measurements and Applications to round off the year.

Last year, our scientists continued to push ahead with our research projects. In this annual report we would like to present an exciting selection of projects from the six business units.

We hope you enjoy it!

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HIGHLIGHTS OF THE YEAR

2019

Remagen, Germany, July 5-12
11th International Summer School on Radar/SAR

FROM 16 COUNTRIES TO THE RHINE

It was already the 11th time that Fraunhofer FHR organized the International Summer School on Radar/SAR. 45 participants from 16 nations came to »Haus Humboldtstein« in Remagen from July 5 to 12 for intensive training and an in-depth exchange of knowledge in the radar/SAR area. A high-class agenda awaited the students, postgraduates and young scientists, including 10 presentations and one of six 1.5-day workshops held by international radar experts. The program also included a visit to the institute. Colleagues of different departments displayed great enthusiasm as they gave presentations, organized tours of the measuring chambers, and showed their projects to the guests. Social life was well accounted for as well: A trip to Cologne, a bike tour around the Rhine River in Bonn, or the traditional »Bergfest«, a barbecue at »Haus Humboldtstein«, provided plenty of opportunities for networking and a lively exchange among everyone.

Paris, France, September 29 - October 4
European Microwave Week (EuMW)

RADAR INNOVATIONS UNDER THE EIFEL TOWER

Fraunhofer FHR sent a large team to represent the institute at the European Microwave Week in Paris at the end of September, sharing a booth with the Dutch Organization for Applied Scientific Research (TNO) and the Fraunhofer Institute for Applied Solid State Physics IAF and another one with the Research Fab Microelectronics Germany FMD. Our experts presented the projects GESTRA, ATRIUM and ORAS, among others, and also gave six specialist presentations, held a workshop, and contributed to two more radar and high frequency subjects at this leading trade show and conference for microwave technology, high frequency techniques, and radar.

Cologne, Germany, October 19
Ceremony to commemorate the IEEE Milestone for the Christian Hülsmeyer Medal

IEEE MILESTONE FOR CHRISTIAN HÜLSMEYER

The »Institute of Electrical and Electronics Engineers (IEEE)«, the world's largest professional association of engineers honored the radar pioneer Christian Hülsmeyer at a historic site in Cologne. On May 17, 1904, the inventor Hülsmeyer, who was only 22 years old at the time, demonstrated his »Telemobiloskop« for the first time at the Hohenzollern Bridge, reliably locating ships even in darkness and foggy conditions. With the support of Fraunhofer FKIE and Fraunhofer FHR, the IEEE has now included this birth of radar as an IEEE Milestone, a very special honor, as to date, only five technical achievements have received this award in Germany. After a ceremony with Cologne's mayor Henriette Reker in the historic city hall, the commemorative plaque was unveiled by the Rhine River on October 19. International radar experts gave speeches about the significance of Hülsmeyer's invention during the evening event.

2019

JANUARY

Darmstadt, Germany, January 22-24
ESA NEO and Debris Detection Conference

FEBRUARY

Wachtberg, Germany, February 21
TIRA image of Tiangong-1 published in Brockhaus Encyclopedia

Wachtberg, Germany, February 26
Radar internship at Fraunhofer FHR with students from RWTH Aachen

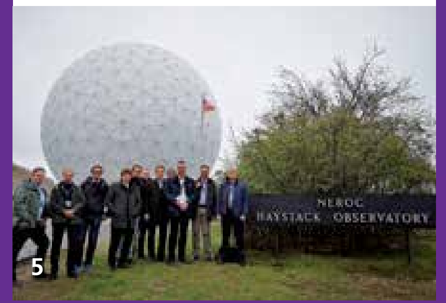
Wachtberg, Germany, February 27
Sinzig's triumvirate visits the institute, with our colleague Dirk Wedhorn as the farmer

MARCH

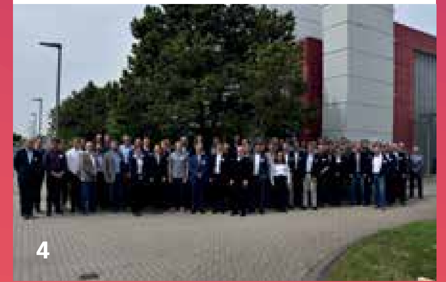
Berlin, Germany, March 14-15
Future Security

APRIL

Boston, USA, April 22-26
IEEE Radar Conference and tour of the HUSIR (Haystack Ultrawideband Satellite Imaging Radar) space radar



Wachtberg, Germany, April 23-24
Counter-UAS Symposium



WDR radio show »ZeitZeichen«, April 30
115 years of radar – radio interview with Prof. Ender about the inventor Christian Hülsmeyer

MAY

Stuttgart, Germany, May 7-10
Control

Wachtberg, Germany, May 7-8
PCL Focus Days

Salamanca, Spain, May 8
Nato Early Career Award for Daniel O'Hagan

San Diego, USA, May 17
IEEE medal for Richard Klemm

Stuttgart, Germany, May 21-23
Automotive Testing Expo: A successful premier with ATRIUM

JUNE

Bonn, Germany, June 4-5
SGW Forum UNMANNED SYSTEMS

Koblenz, Germany, June 15
Open door day of the Federal Armed Forces

Wachtberg, Germany, June 20
The District Administrator of the Rhein-Sieg District, Sebastian Schuster, visits Fraunhofer FHR

Ulm, Germany, June 26-28
International Radar Symposium (IRS)

JULY

Aachen, Germany, July 3
Bonding Automotive Day

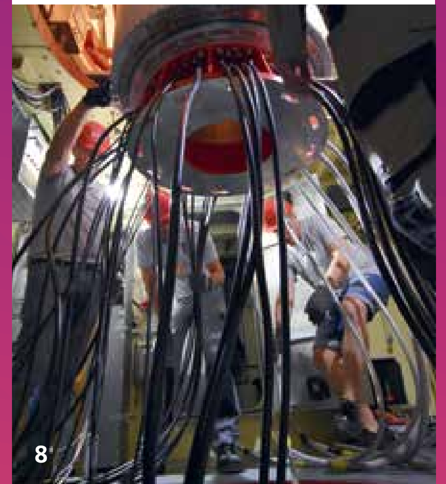
Wachtberg, Germany, July 4
Wachtberg Forum (see page 12)

Wachtberg, Germany, July 5
Inspector General Inquires about Space Observation
High-ranking visitor in Wachtberg: The Inspector General of the Federal Armed Forces visited the institute for the first time. Prof. Knott took General Eberhard Zorn on a guided tour of the premises and presented the capabilities of TIRA and GESTRA. The General was impressed by the performance of the systems and emphasized their contribution to the protection of space infrastructure. Fraunhofer FHR is an important partner for the Federal Armed Forces within the scope of the federal government's space strategy. »It was an honor for us to be able to welcome the Inspector General of the Federal Armed Forces for the first time. And we are looking forward to continuing our constructive and successful cooperation with the Armed Forces,« said Prof. Knott as he thanked General Zorn for his interest.

Wachtberg, Germany, July 5
Advisory Board meeting

Remagen, Germany, July 5 – 12
11th International Summer School on Radar/SAR

Wachtberg, Germany, July 9
After 50 years, the space observation radar TIRA gets a new slip ring



AUGUST

Cologne, Germany, August 13
ICPS Job fair

Eckernförde, Germany, August 29
Final Presentation: Fraunhofer FHR develops novel multiband antennas for the ship radar SEERAD

SEPTEMBER

Koblenz, Germany, September 5
AFCEA Award for Giovanni D'Apice

Munich, Germany, September 9
Cooperation agreement between the University of Siegen and Fraunhofer FHR for the creation of joint professorships

Frankfurt, Germany, September 10-13
International Automobile Exhibition (IAA)

Bonn, Germany, September 12
Company run

Frankfurt/Oder, Germany, September 12-13
FMD Innovation Day

Bonn, Germany, September 17-21
Highlights of Physics: TIRA and GESTRA at the science festival

Ulm, Germany, September 25
ARGUS AWARD 2019 for Jannik Springer

OCTOBER

Bonn, Germany, October 10
Career Day

Bonn, Germany, October 16-17
ELIV (Electronics in Vehicles): High frequency technology for autonomous driving

Düsseldorf, Germany, October 16-23
K-MESSE
At the K 2019, the world's leading trade fair for the plastics and rubber industry in Düsseldorf from October 16-23, our colleagues presented the capabilities of the millimeter wave scanner SAMMI®, which was developed at Fraunhofer FHR. Right in front of the intrigued professional visitors, who were also allowed to bring samples to the booth themselves, SAMMI® scanned a large variety of plastic products, inspecting them for contamination, air inclusions, internal structure, shape, density, homogeneity and much more. Visit the Fraunhofer FHR YouTube channel for an exciting video of the trade fair; it's well worth having a look!

Cologne, Germany, October 19
Ceremony to commemorate the IEEE Milestone for the Christian Hülsmeyer Medal (see page 6)

Bali, Indonesia, October 25
IEEE Award for Andrej Konforta, Christos Liontas, and Prof. Dr. Thomas Eibert (TUM)

NOVEMBER

Aachen, Germany, November 7
Bonding

Wachtberg, Germany November 8
Technology Night Bonn-Rhein-Sieg

Brussels, Belgium, November 14
EDA-Workshop »Radar Signatures & EM Benchmarks«

Bremen, Germany, November 19-21
Space Tech Expo Europe: Space Capabilities under the Spotlight

Wachtberg, Germany, November 27
New era in space surveillance:
A new era in space surveillance: With the support of the space observation radar TIRA, the GESTRA radar system, developed and built on behalf of the Space Administration in the German Aerospace Center (DLR), received the first signals from space objects (see page 43).

DECEMBER

Ulm, Germany, December 4-5
VDI Conference »Sensoren für mobile Maschinen«

WACHTBERG-FORUM MARKED BY THREE ANNIVERSARIES

70 years of Fraunhofer-Gesellschaft, 10 years of Fraunhofer FHR, 5 years of Cognitive Radar: 2019 didn't only bring the Fraunhofer-Gesellschaft's big anniversary, but also two more reasons for the institute to celebrate in 2019. The 9th Wachtberg-Forum on July 4th provided the appropriate setting.

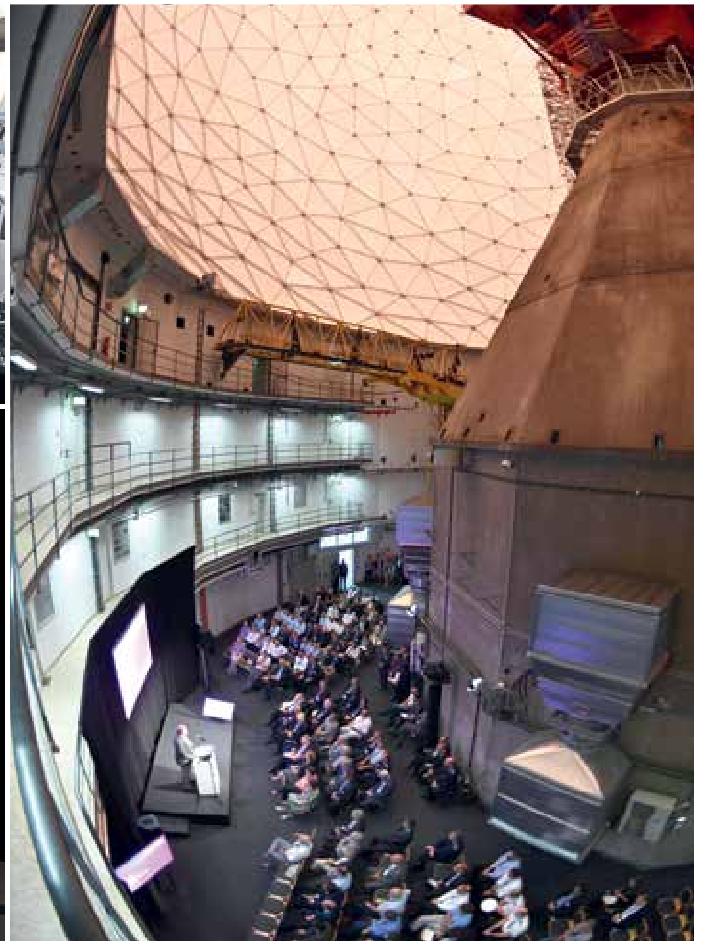
Fraunhofer FHR celebrated one decade as part of the Fraunhofer-Gesellschaft at the Wachtberg-Forum 2019. The institutes of the Forschungsgesellschaft für Angewandte Naturwissenschaften (FGAN) were integrated into the Fraunhofer-Gesellschaft in 2009. Since then, numerous renowned research and development projects have been completed with partners in industry and science, while Fraunhofer FHR saw its budget double to 38.4 million euros and its staff size increase from about 200 to more than 350.

The Wachtberg-Forum was created for orders from industry as a platform for the communication with customers and clients the same time the institute was opened. FHR has been presenting its newest developments and future prospects in the field of radar research with an exhibition and presentation area at the Forum every year since 2010. The Wachtberg-Forum 2019 was the largest one to date: Nearly 200 professional visitors made their way to the institute's premises that features the »ball«, the highly visible space observation radar TIRA. The scientists of Fraunhofer FHR showcased the versatile applications of radar in a clear and practical manner. Space observation with radar, drone defense systems and applications to increase the safety of autonomous vehicles took center stage.

Politics, Science, and Defense recognize the development of the Institute

Welcome speeches were held by Susanne Schneider-Salomon, Group Manager of Non-university Research Organizations in the Ministry of Culture and Science of North Rhine-Westphalia, Lieutenant General Klaus Habersetzer, Air Operations Center Commander, Renate Offergeld, Mayor of Wachtberg, Elisabeth Ewen, Human Resources Director of the Fraunhofer-Gesellschaft, and Prof. Dr. Peter Martini, Deputy Chairman of the Fraunhofer Group for Defense and Security VVS and Head of Institute of Fraunhofer FKIE. In addition, Dr. Norbert Röttgen, Member of the German Parliament, Sebastian Schuster, District Administrator of the Rhein-Sieg District, and Oliver Krauß, Member of the State Parliament, were there to catch up on Fraunhofer FHR's newest innovations.

Susanne Schneider-Salomon of the Ministry of Culture and Science congratulated the institute in the name of the state: »I would like to congratulate the institute for its success. We are proud of having Europe's leading institute for high frequency physics and radar techniques in North Rhine-Westphalia – particularly in light of the scientific achievements that back the rapidly increasing budget and staff numbers.«



Lieutenant General Klaus Habersetzer emphasized the important role of Fraunhofer FHR as a key partner of the Federal Armed Forces: »Your products are an important basis for the work done in the Space Situational Awareness Center. Your expertise and know-how are at the highest level. This is something we can rely on. Thank you very much for this.«

The headquarters of the Fraunhofer-Gesellschaft views the ten years of Fraunhofer FHR in an entirely positive light: »The integration of the institute into the Fraunhofer-Gesellschaft was the right decision. Dual-use subjects, developments originally made for the military, are increasingly used for the civil sector, where they become successful or even turn into game changers,« said Elisabeth Ewen in the name of the Fraunhofer Board.

The two Institute Directors Prof. Dr. Peter Knott and Prof. Dr. Dirk Heberling also come to a gratifying conclusion: »Under the umbrella of the Fraunhofer-Gesellschaft, the institute successfully took the step into the free market. We are proud of the last ten years and happy to be a reliable partner for the defense and security sector as well as a competent point of contact for solutions in industry and business,« comments Prof. Knott on the anniversary. »Without our staff, who have been fully committed and willing to break new ground, this success story would not be possible,« adds Prof. Heberling.

Excellent Development of the Cognitive Radar Department

The Wachtberg Forum also celebrated the 5th anniversary of the Cognitive Radar Department at Fraunhofer FHR. The new Cognitive Radar Department was created in 2014, on the initiative of the Institute Director at the time, Prof. Dr. Joachim Ender. Prof. Ender recognized the paradigm shift and the potential the use of artificial intelligence had in radar signal processing, moving away from classical analytical procedures and toward data-driven approaches. In addition, the automotive and aviation industries saw the emergency of the trend toward autonomous systems, which could also be applied to a highly automated radar system. Dr.-Ing. Stefan Brüggenwirth assumed the management of the new department.

A lot has been achieved in the last five years: To establish Fraunhofer FHR as the world's leading player in this new field of research, the department had to develop an excellent expertise in the subject of artificial intelligence and high-level information processing. Thanks to the early initiative of Prof. Ender and the strategy of employing staff with a background in computer sciences, AI, or machine learning, Fraunhofer FHR was well-positioned in this now fully established research field right from the start. In 2020, the institute boasts one of the largest research departments for cognitive radar in the world. Milestones include the joint definition of a cognitive radar architecture with industry and the recently published IEEE AESS Special Issue on cognitive radar.

Since 2014, the department's staff has increased from 14 to 31. The future prospects are excellent as the trend toward AI and autonomous systems continues. In this process, the challenge remains of attracting the best minds in the AI area. »In this aspect, the young, dynamic team and the exciting research topic have allowed the department to grow continuously, and this is what we expect to see in the future as well,« says Dr. Stefan Brüggenwirth about the 5th anniversary of his department.

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FRAUNHOFER MINDS
AT FRAUNHOFER FHR

Fraunhofer is diversity. Fraunhofer is future. Fraunhofer is excellence. In the year of its 70th anniversary, the Fraunhofer-Gesellschaft launched the project »70 years. 70 minds«. It places the focus on Fraunhofer's staff – the diverse range of people with their diverse excellence engaged in working and researching for the future.

70 YEARS OF FRAUNHOFER
70 YEARS OF FUTURE
#WHATSNEXT

»We need a whole range of intelligent ideas to tackle the major challenges of our times: e. g. the environmentally friendly generation and storage of energy! The general task consists in forming cross-location, interdisciplinary research teams. Searching for creative solutions together with people from very different cultural backgrounds – this is what I am especially excited about in the future increasingly networked world of the future.«

70 YEARS OF FUTURE
#WHATSNEXT

DR. DIRK NÜßLER
HEAD OF DEPARTMENT INTEGRATED CIRCUITS AND SENSOR SYSTEMS

Dr. Dirk Nüßler is the Head of Department Integrated Circuits and Sensor Systems at the Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR in Wachtberg, North Rhine-Westphalia. He is committed to advancing the development of radar systems, e. g. compact, intelligent sensors for production monitoring.

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#WHATSNEXT
THOMAS DALLMANN
TEAMLEADER
RESEARCH GROUP AACHEN

Dr.-Ing. Thomas Dallmann is the Team Leader of the Research Group Aachen of the Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR. Dallmann spoke about the knowledge exchange between universities and applied research and the future of radar systems during an on-site visit.

»We bring fresh air in radar research!«

70 YEARS OF FUTURE
#WHATSNEXT

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THE FUTURE ON THE RADAR

The future is being created in Melatener Street in Aachen, in a building that – of all things – seems to have fallen out of time. The freestanding university building belongs to RWTH Aachen, Germany's largest university for technical degrees. This is where Thomas Dallmann works with his research group, which is actually part of the Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR in Wachtberg. Thomas Dallmann, who is in his mid-thirties, takes his visitors to the first floor of the institute to present a core element of his work.

Dallmann reports on a research project that makes it easier than before for customers in the automotive sector and for suppliers to test new radars. ATRIUM is a type of virtual environment that can be adapted to a wide range of different vehicle types to accurately examine the behavior of a new technology even in complex traffic situations – for a faster, more cost-efficient development of new, error-free radars. After all, radar sensors will become even more relevant in the future as they, instead of the passengers, continuously monitor traffic in driverless cars. Today radar sensors already recognize obstacles by themselves to initiate braking actions. »These types of sensors are currently being tested by driving thousands of kilometers.« Thomas Dallmann stares out of the window, lost in thought. »This is an extremely time-consuming and cost-intense process – a process that still leaves a lot to be desired.« With ATRIUM, many of these tests can be moved to the lab; this can be shown with the simulator version connected here today. »Using radar target sensors, we can replicate driving scenarios to simulate entire echo landscapes,« explains Dallmann. »Radar sensors based on sending signals and then receiving their reflections need these echo landscapes to be able to detect and analyze the surrounding objects by means of the received signals.« People, traffic lights, trees, cars: Dallmann is certain that ATRIUM will soon be capable of generating up 300 reflections. »With this, we can fully and realistically test new sensors for autonomous driving.«

Thomas Dallmann is confident that the presence of radar systems is set to increase – way beyond the field of autonomous driving. »Radar networks are becoming increasingly relevant – especially in light of intelligent, networked factories that will barely be able to function without radar,« says the scientist. Overall, however, the applications are getting smaller and smaller – as with the gesture-controlled Google smartphone Pixel 4, which already recognizes small finger movements with the radar chip 'Soli'.

Incidentally, Dallmann himself already participated in the German youth science competition »Jugend forscht« with a radio direction finding system before studying Electrical Engineering and Information Technology at the University of Excellence RWTH Aachen. After that, he first worked for RWTH's Institute of High Frequency Technology as a Research Scientist and then as the Team Leader of Fraunhofer FHR's Research Group Aachen.»Our location right in the middle of the university, kind of like a Fraunhofer satellite, provides a knowledge transfer that is equally beneficial for both research and the university.« The researcher starts to gush on the drive to the Fraunhofer Institute in Wachtberg. »Fraunhofer FHR is one of the world's largest radar institutes. It is impressive to see the huge range here, that radar technology offers in research and in application.«

The Fraunhofer Institute Thomas Dallmann belongs to is located in Wachtberg, near Bonn, and can be recognized from afar thanks to its special landmark: With its 47.5 meters in diameter, it's impossible to miss the circular radar dome of the space observation radar TIRA. TIRA is used to help develop radar techniques to capture and reconnoiter objects in space – from intercontinental missiles all the way to electronics waste – for space agencies around the world. It is rare, however, to find the researcher inside the ball, which is unique in all of Europe: While the radome on site is the world's largest, he and his research group, quite to the contrary, work on the smallest of radar applications in the form of sensors. But Thomas Dallmann is absolutely certain: »They will also make it big now!«

DOCTORAL STUDIES AT FRAUNHOFER FHR

Fraunhofer FHR offers optimal conditions for scientists to write their dissertation at the institute. In doing so, the Institute provides the staff members with support tailored to their individual interests and their road to their doctorate. Two colleagues who received their doctorates in 2019 report on their experiences.

DR. BENEDIKT WELP

System concepts and circuits for broadband MIMO FMCW radar systems up to 60 GHz in modern SiGe bipolar technologies

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Dr. Benedikt Welp came to Fraunhofer FHR from Ruhr-Universität Bochum in March 2013. After writing his master thesis in Electrical Engineering and Information Technology with Professor Nils Pohl, he received the offer from Wachtberg to set up a new team for chip design in Prof. Pohl's former department (now ISS Department). **»When I began working here, the complete infrastructure of the new team had to be set up, as I was the first member of this team. We also had to develop chips for our partners in industry – from obtaining the right software to setting up the labs with chip measuring technology all the way to the development of the first SiGe chips designed at Fraunhofer FHR,«** says Dr. Benedikt Welp.

The 31-year old has had the idea of doing his doctorate for quite some time. After having worked on several projects with industry customers and on public research projects, his thesis' focus on the area of broadband signal generation with high output power for FMCW radar systems started to become apparent. This is how he found his dissertation subject titled »System concept and circuit for broadband MIMO FMCW radar systems up to 60 GHs in modern SiGe bipolar technologies«.

His thesis focused on research for projects in the field of high frequency and radar techniques and within the scope of the Federal Aviation Research Program (LuFo) of the Federal Ministry of Economics and Energy. **»In addition to project work for customers, it was especially my boss and doctoral supervisor who made it possible for me to work on my dissertation independently. Strong intrinsic motivation and the ability to work independently surely don't do any harm to set out to earn one's doctorate. All the while, the chip design team, Dr. Dirk Nüßler and Prof. Pohl as my bosses, always had an open ear for questions and new ideas I wanted to try. The institute opened up many opportunities for me, I was able to publish articles and had the chance to participate in international conventions, for example in Hawaii, and to exchange knowledge with experts from around the world. This was extremely attractive for me as a scientist. I'm also particularly happy that my research work has led to new projects, customers, and applications,«** says Dr. Benedikt Welp to sum up the doctorate he completed in January 2019.

DR. PHILIPP WOJACZEK

Passive Radar on Moving Platforms Exploiting DVB-T Transmitters of Opportunity

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Dr. Philipp Wojaczek joined Fraunhofer FHR right after university. After studying Electrical Engineering, Electronics, and Information Technology at the Friedrich-Alexander University Erlangen-Nuremberg, he set out for his career at the institute on March 1., 2015, where he now conducts research in the PSR Department. **»My Team Leader Dr. Diego Cristallini suggested doing my doctorate with Prof. Pierfrancesco Lombardo at the Sapienza University of Rome. I knew Prof. Lombardo through his lecture at the International Summer School on Radar/SAR and so I applied for the three-year doctoral program in Rome,«**, says Dr. Philipp Wojaczek. After his application was successful and he presented himself to a consortium of professors in Rome, he was accepted as a PhD student.

He found the subject for his doctor thesis, titled »Passive Radar on Moving Platforms Exploiting DVB-T Transmitters of Opportunity« through his research work at Fraunhofer FHR. **»The field of passive radar on moving platforms is one I find particularly exciting because there hasn't been and there is not much research on it yet. So I had the freedom and the challenge of starting a lot from the ground up,«** says the 32-year old.

The cooperation with the university in Italy went smoothly. **»I sent my results to Italy and we held regular conference calls. I also had the chance of meeting up and talking with Prof. Lombardo on a personal level at the Summer School and at conferences. The opportunity of working at the faculty in Rome together with other PhD students and Prof. Lombardo in the second year was also very valuable,«** says Dr. Philipp Wojaczek. After submitting his dissertation, he defended it in Rome in February 2019. **»All in all, the conditions for my doctoral studies were excellent. The institute fully supported me in each phase of my doctoral thesis and my team was always there for me when I had questions. My research work in the PSR Department provided me with the necessary key data for my thesis which formed the bases for me to develop my simulations,«**, summarizes Dr. Philipp Wojaczek.

FRAUNHOFER FHR IN PROFILE

Fraunhofer FHR is one of the leading and largest European research institutes in the area of high frequency and radar techniques. It develops customized electromagnetic sensor concepts, processes, and systems for its partners, from the microwave range through to the lower terahertz range.

The core topic of the research at Fraunhofer FHR consists of sensors for high-precision distance and position determination as well as imaging systems with a resolution of up to 3.75 mm. The applications range from systems for reconnaissance, surveillance, and protection to real-time capable sensors for traffic and navigation as well as quality assurance and non-destructive testing. Fraunhofer FHR's systems are characterized by reliability and robustness: Radar and millimeter wave sensors are suitable for demanding tasks, even under rough environmental conditions. They work at high temperatures, with vibrations, or under zero visibility conditions caused by smoke, vapor, or fog. Thus, radar and the related high frequency systems, are also key technologies for defense and security. In this area, the institute has been supporting the German Federal Ministry of Defence (BMVg) since the institute was founded in 1957.

On one hand, the processes and systems developed at Fraunhofer FHR are used for research of new technology and design. On the other hand, together with companies, authorities, and other public entities, the institute develops prototypes to unsolved challenges. The special focus here is on the maturity of the systems and their suitability for serial production to ensure a quick transformation into a finished product in cooperation with a partner. Thanks to its interdisciplinary positioning, the institute possesses the technical know-how to cover the entire value creation chain, from consulting and studies up to the development and production of pilot series. The used technology ranges from the traditional waveguide base to highly integrated silicon-germanium chips with a frequency of up to 300 GHz.

The ability to carry out non-contact measurements and the penetration of materials open up a range of possibilities for the localization of objects and people. Thanks to the advances in miniaturization and digitalization, the high frequency sensors of Fraunhofer FHR with their special capacities are an affordable and attractive option for an increasing number of application areas.

Staff and Budget Development

The institute's budget comes from several sources of financing: The basic financing from the German Federal Ministry of Defence (BMVg), the project financing through funds from the defense budget and the income from the contract research area (Vfa), which in turn can be subdivided into economic revenues, public revenues, EU revenues, others, and the basic financing by the federal government and the federal states. In 2019, in its defense and civil segments, Fraunhofer FHR generated total revenues of 39.0 million euros.

Fraunhofer FHR had a total of 374 employees by the end of 2019, a 5.9 % increase compared to the previous year. Of these, 196 are permanent employees and 123 are temporary employees. The 55 remaining employees are students and apprentices.

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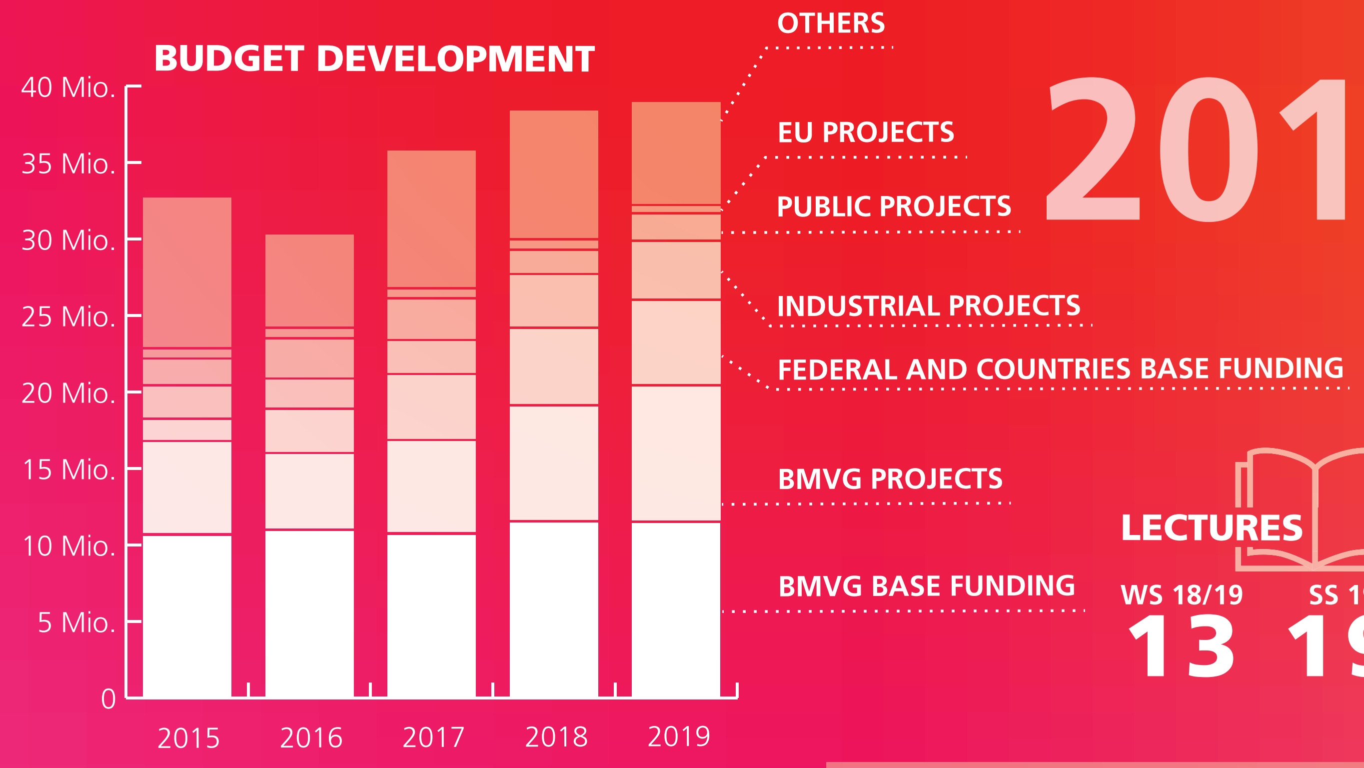
OVERVIEW

FRAUNHOFER FHR IN NUMBERS

BUDGET DEVELOPMENT



2019

LECTURES

WS 18/19 **13**

SS 19 **19**

DEGREE THESIS

22 MASTER

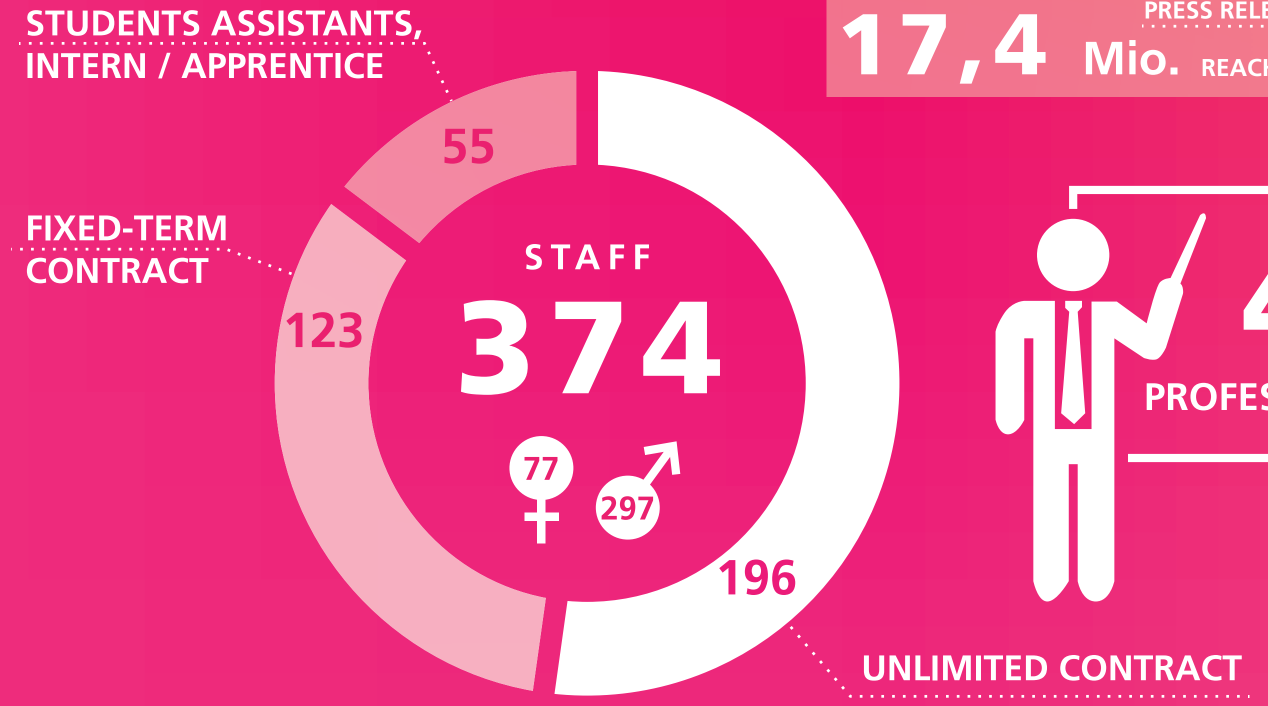
7 PHD

MEDIA ANALYSIS

58 ARTICLES IN THE MEDIA

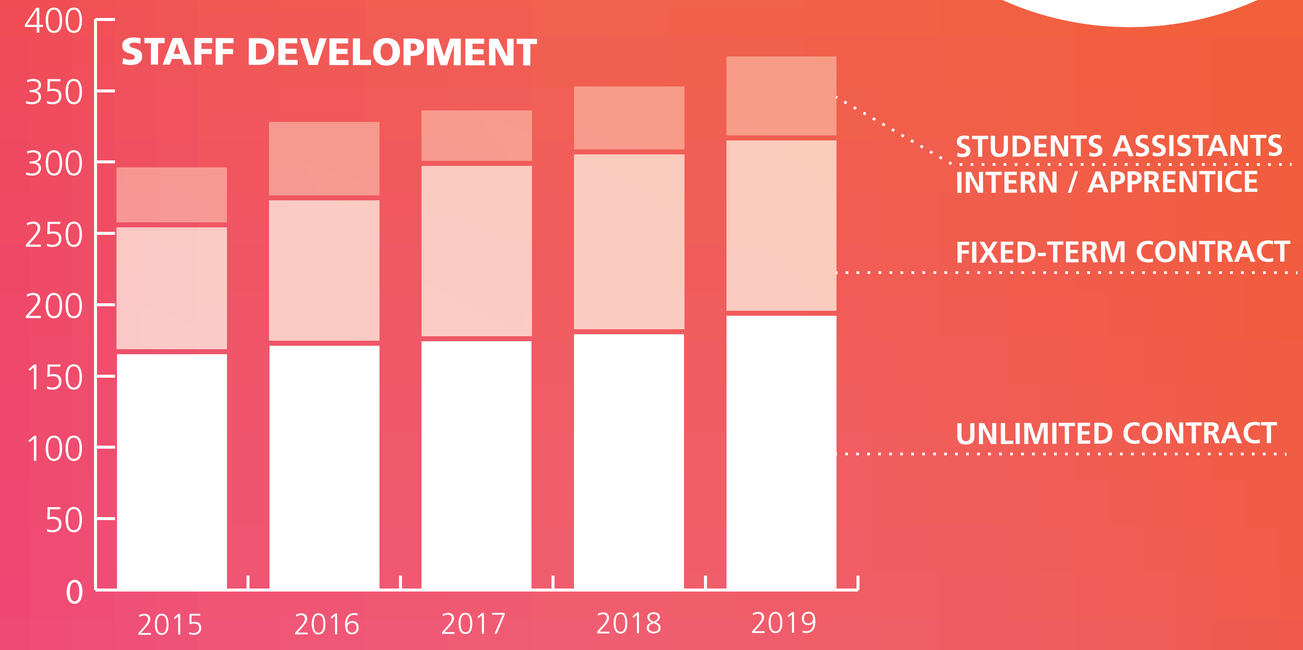
15 PRESS RELEASE

17,4 Mio. REACHED CONTACTS



4 PROFESSORSHIP

STAFF DEVELOPMENT



German 1399
Englisch 1471

880

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1090

128

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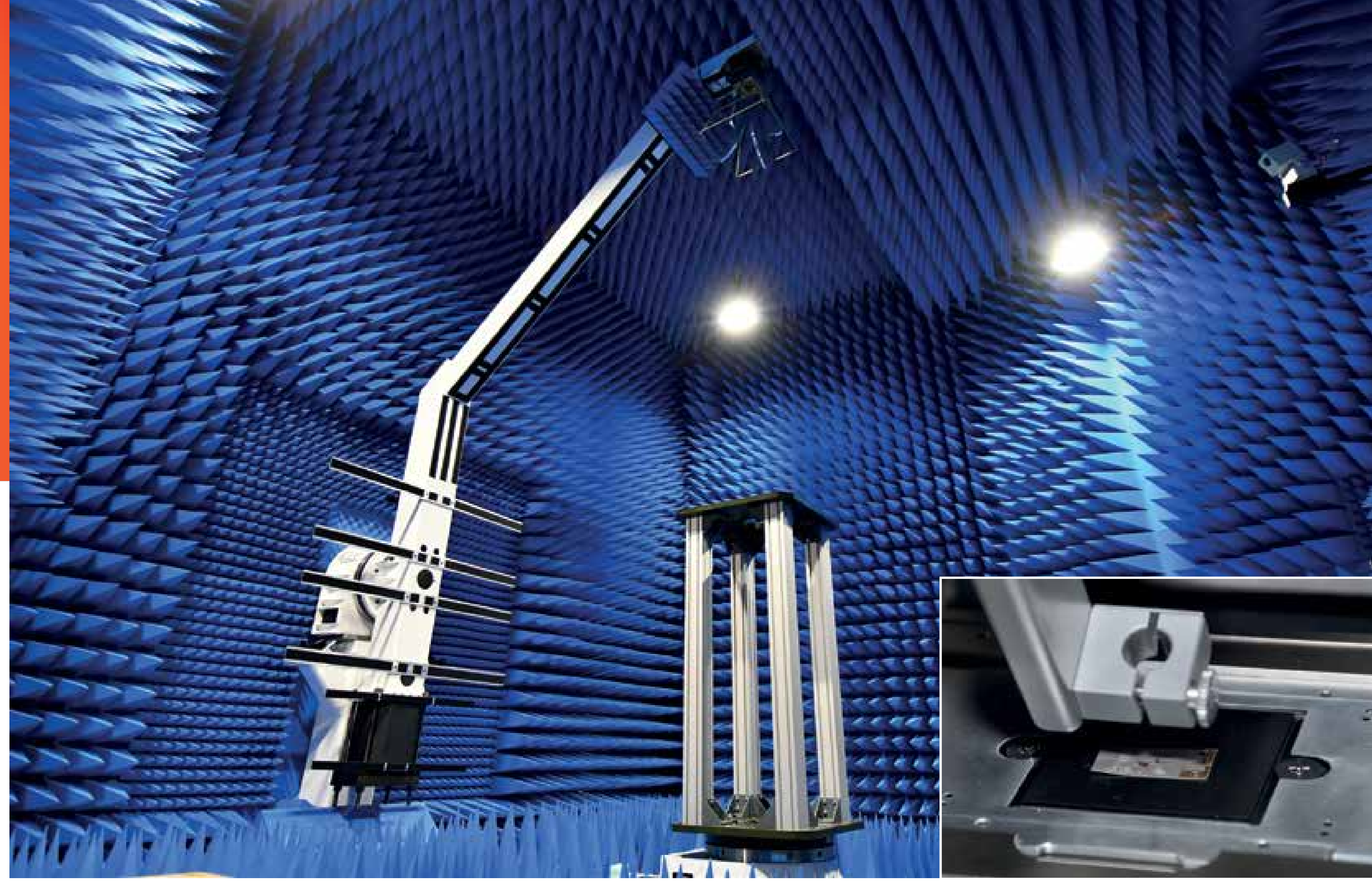
Attendees of the Advisory Board meeting on July 5, 2019 on the institute's premises in Wachtberg: Ms. Ewen (Fraunhofer Headquarters), Prof. Waldschmidt, Dr. Weber (Fraunhofer Headquarters), Prof. Heberling (Director Fraunhofer FHR), Prof. Loffeld, Mr. Pappert, Mr. Wetjen, Dr. Elsbacher, Mr. Neppig (Federal Armed Forces), Mr. Hommel.



Spherical near field antenna measuring facility of the companies NSI-MI and Telemeter for the high-precision characterization of antennas in complex radar systems. Bottom right: Finetech die placer FINEPLACER® pico during the processing of a high frequency printed circuit board.

RESEARCH FAB MICROELECTRONICS GERMANY (FMD)

Companies need perseverance for developments in the semiconductor segment: Numerous individual institutes have to be contracted. For this reason, the Research Fab Microelectronics Germany has now combined the expertise of different research institutes, including Fraunhofer FHR. Thanks to a number of new acquisitions, technologies can now be used that were not available before in Germany.sion characterization of antennas in complex radar systems. Bottom right: Finetech die placer FINEPLACER® pico during the processing of a high frequency printed circuit board.

When medium-sized businesses or start-ups need developments in the semiconductor segment, they are often faced with difficulties. After all, it is rare for a single research institute to cover all required competencies. For companies, this means the following: They have to contact multiple institutes and conclude many individual contracts – a tremendous effort. This is where the Research Fab Microelectronics Germany, FMD in short, comes in: Following the example of large microelectronics institutes abroad, it combines the German competencies, establishing a joint virtual structure. The cooperation is made up of eleven Fraunhofer Institutes of the Fraunhofer Group for Microelectronics and the two Leibniz Institutes FBH and IHP. The Federal Ministry of Education and Research (BMBF) provided a total 350 million euros in funding for the creation of the FMD – in particular to close the technological gaps between the institutes and to introduce technologies which had not been available yet in Germany. Fraunhofer FHR primarily contributes its expertise in the areas of high frequency techniques, antenna measurement technology, and the production of circuit boards, radar modules, and high frequency structures.

Customers get to enjoy the direct benefits of this cooperation. They only have to contact one contact person, they receive a single contract, and they obtain the entire development chain from a single source. Let's take a radar chip as an example: For instance, the circuit design would be done by FHR, the production at IHP in Frankfurt/Oder or at Fraunhofer IAF in Freiburg, the packaging would be done at Fraunhofer IZM in Berlin, and finally, Fraunhofer FHR would have to get involved again for the radar and antenna inspection. The company would only negotiate with FMD for this entire chain.

Antenna Measurement Chamber for Complex Radar Systems

One of the key competencies Fraunhofer FHR contributes to FMD is antenna measurement technology. What are the properties of antennas for radar systems – for example, what are their directional characteristics? In the future, an antenna measurement chamber acquired within the scope of the FMD will allow for accurate examinations of individual and array antennas in the frequency range from 300 MHz to 50 GHz. The chamber itself has been completed. The range assessment is currently still in progress – that is the verification of the test area. This involves the measurement chamber being characterized according to specified criteria in order to be able to prove the quality of the measurements. As of late, even the smallest of antennas can be analyzed at Fraunhofer FHR using FMD infrastructure: For instance on-chip antennas, i.e. antennas with a size of one to two millimeters integrated into a chip.

Additive Manufacturing of High Frequency Circuit Boards

Another new acquisition addresses the additive manufacturing of high frequency structures: industrial-scale metal and plastic printers. Whereas the 3D printers we are familiar with from at home are only capable of producing small structures and low quantities, these printers make it possible to produce volumes of up to one cubic meter. Another special feature: The metal printer is also capable of printing waveguide structures. The plastic printer opens numerous new possibilities as well: for example printing antenna structures, lenses, and housings. The devices are to be set up in a facility specifically rented for this purpose in July of 2020.

Producing Printed Circuit Board Prototypes on Short Notice

Thanks to the FMD's investment resources, FHR was able to acquire a variety of devices, including a laser milling machine, placers and bonders, to produce printed circuit boards – quickly and on short notice. This enables Fraunhofer FHR to create subsystems – e. g. for signal generation – as well as entire systems, e. g. a complete radar system. The construction and integration technology equipment pool was expanded for this purpose. An anechoic chamber covering the range from eight GHz to one THz provides for the possibility of testing the manufactured subsystems. A climate test chamber complements the measurement possibilities, facilitating the examination of the systems under different temperatures and humidity.

Material Tests

How many radar beams does an object or material reflect and how many penetrate it? This can be examined at different angles of incidence and distances using the RCS measurement. In doing so, both monostatic measurements, in which an antenna emits the signal and also receives the reflected signal, as well as bistatic measurements, with separate transmitting and receiving antennas, are possible.

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- Radar is a key technology for defense – the classic fields of application are air surveillance and image-based remote reconnaissance. In these areas, the Business Unit Defense provides its expertise to support the Federal Armed Forces, among others.
- Radar technology can also be a practical solution in the close range, for example for the active protection of military vehicles.
- Where concealed reconnaissance is required, passive radar – which detects existing radio waves – is an ideal option. The Business Unit Defense has developed the first passive air surveillance system.
- First results were obtained in the field of cognitive radar, which carries out its parameterization itself.

RADAR IN THE SERVICE OF DEFENSE

Reconnaissance in crisis areas, surveillance of the airspace, protection of military vehicles: When it comes to defense, radar is a key technology – after all, it allows for the radio-based detection and measurement of objects. Fraunhofer FHR's Business Unit Defense offers a high degree of expertise in radar technologies that are frequently used by the Federal Armed Forces and the military industry.

Air Space Surveillance and Radar Imaging for Remote Reconnaissance

An important task of the Federal Armed Forces consists in detecting objects in airspace and low Earth orbit, whether these are aircraft, rockets, or even satellites. Therefore, the radar systems developed in the Business Unit Defense on the one hand, monitor the airspace from Earth – with the radar systems looking up into the air from the ground. On the other hand, radar systems mounted on aircraft or satellites monitor Earth from above. Such an image-based distant reconnaissance allows for the measurement of both buildings and other static objects as well as moving objects such as cars and trucks. Another task of radar systems consists in determining target classes. For example, helicopters, rockets, or similar objects are distinguished in the air, while individual buildings and even the types of agricultural areas can be recognized on the ground.

A general trend that is starting to emerge in the radar field: The use of higher frequencies is increasing. On one hand, this makes it possible to implement smaller and lighter radar systems and on the other hand, the usual frequency range is getting crowded due to increasing mobile communications and wireless networks. With its 300-gigahertz radar, the Business Unit Defense is in the big leagues on an international level

Further Radar Developments for Defense

Radar is also a practical solution for some close range issues as well as it is capable of imaging the surroundings even in darkness or foggy conditions. This can be important on drones or other unmanned flying objects, on robots, or on vehicles, for instance. On military vehicles, it is possible to recognize when the vehicle is being fired on: For example, when a grenade is approaching, the tenths or even hundredths of a second are crucial to be able to initiate active protection measures. The Business Unit Defense implements the radar detection of projectiles required for active protection.

Any attempts undertaken by other countries to explore the circumstances in Germany are in no way appreciated. For this reason, the Business Unit Defense also works on deceiving or jamming radar systems with the corresponding transmitters – to impede or prevent any exploration by this means. Passive radar is an ideal solution to conceal one's own observations and to thus protect them against these types of jamming attempts. In doing so, you do not emit the signals yourself but instead use the radio waves of others to monitor the airspace – without making yourself noticeable. The Business Unit Defense was also productive in applying its expertise in this area of concealed reconnaissance: It developed the passive system for air surveillance.

Cognitive radar is still a rather new field of research for the Business Unit Defense. Achieving the optimum setting of a radar system for its use is usually a complex challenge. The aim for the future is for radar to be able to carry out its parameterization itself and adapt it to the task based on its own intelligence since it makes a big difference if images of areas with high mountains or over the ocean with powerful waves have to be obtained. Excellent results have already been achieved in this area of cognitive radar. Other, still relatively new, research fields are the design of metamaterials – i.e. materials with properties that do not exist as such in nature – allowing for special features in antenna design – and coherent radar networks in which multiple transmitters and receivers work together to emit their signals fine-tuned to each other.

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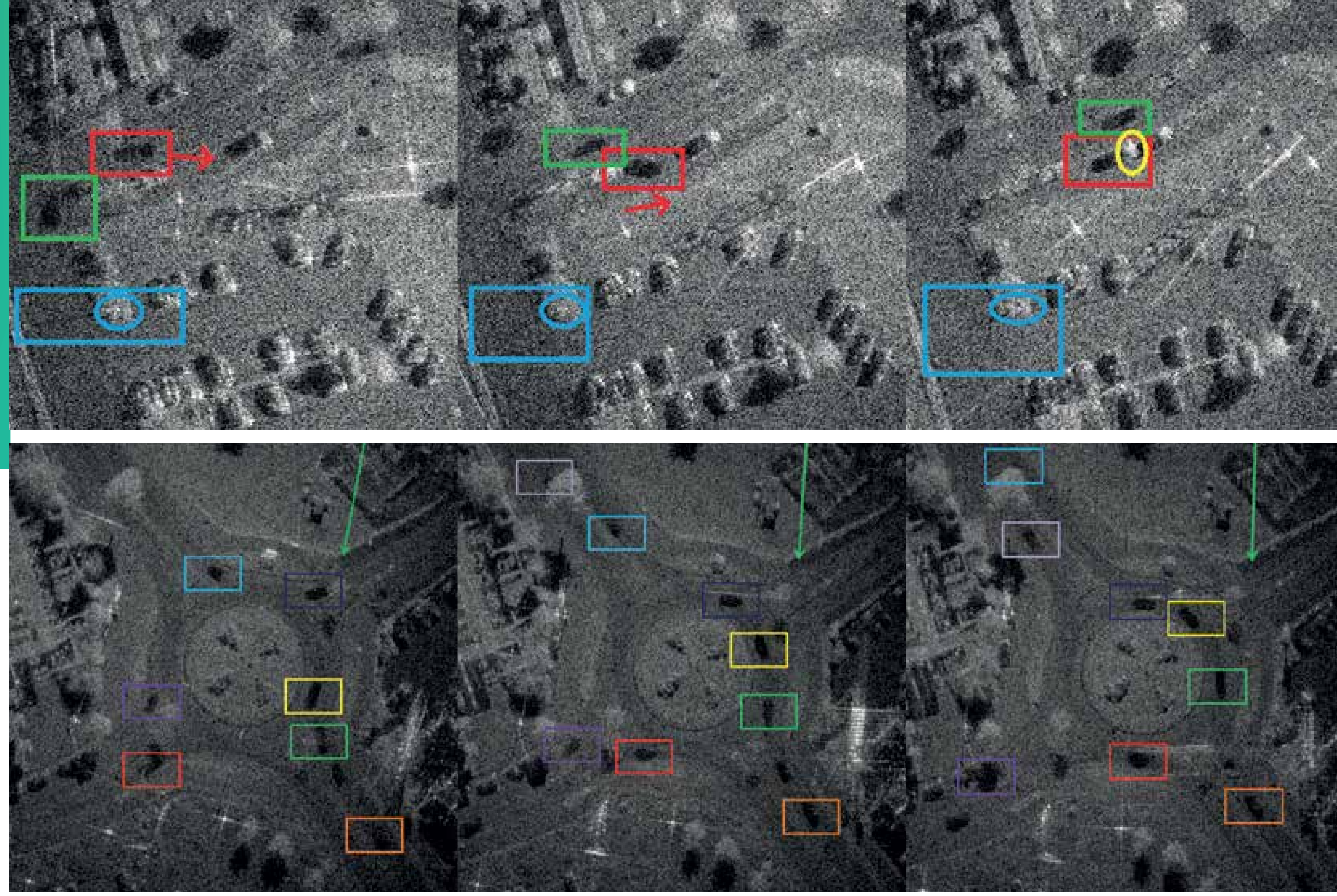

Zoom of a parking lot (above) and a roundabout (below) in a circular SAR video image sequence. In each case, 3 images of the sequence are shown, each a few seconds apart. The different colors show the shadows of moving cars during the illumination. A car can be seen as it is parking (red) above, while down below the traffic in the roundabout can be tracked based on the shadows.

HIGHER RESOLUTION, THREE-DIMENSIONAL IMAGES: CIRCULAR SAR

To obtain an image of a terrain from an aircraft with the highest possible resolution, it is best to fly over this terrain in circles. Accordingly, Fraunhofer FHR has developed a circular SAR: It operates at 94 gigahertz, achieving a very high resolution. In addition, it is capable of providing 3D images and even capturing the shape of moving objects, even when using single-channel radar.

We know it from driving: When we drive past an object, we only get a relatively fleeting glimpse of it. But if we drive around the object in circles, we have the time to get a look at it from all sides. The same applies to radar imaging. With Synthetic Aperture Radar, SAR in short, you usually fly across an object in a straight line – since this allows for easy imaging – recording the radar data in the process. In contrast, with circular SAR, the aircraft takes a circular path over the area to be observed. While this makes the signal processing more challenging, a specific terrain can be illuminated for a long period of time – and, as usual for radar, even in darkness and through cloud covers.

Significantly Higher Resolution Possible

This longer data collection has a significant effect on the image resolution: While the lateral resolution is physically limited with the linear SAR due to the antenna aperture, mostly being in the range of a few centimeters, the resolution for the circular SAR can theoretically be increased up to a wavelength range of three millimeters. The reason for this: When flying over an area on a linear path, target objects are only seen from a small angle range – the number of viewing angles is naturally limited and the data can be collected across a shorter angle range. Objects concealed by trees or buildings might only be barely recognizable or not at all. But by circling around the target area, the object can be seen from all sides and the signals from different angles can be effectively combined with each other. In addition to the high resolution, this also allows for the generation of a three-dimensional image with a single-channel system. Such a single-channel measurement is especially useful when the flood of data is to be kept low and the measurement is to be made as simple as possible. After all, using two channels for a measurement creates twice the data, with the corresponding extra signal processing load.

The frequency of Fraunhofer FHR's circular SAR is 94 gigahertz – a unique feature since other circular SAR systems operate at significantly lower frequencies. The advantage of the high frequency: The wavelength of the signals is smaller, shorter illumination times can be chosen and higher resolutions are possible. The resolution achieved in practice is currently around two centimeters. Another distinctive feature of Fraunhofer FHR's circular SAR: Regardless of how the aircraft is moving, the radar systems keep targeting the same spot on the ground. This is made possible by a gimbal – a structure on which the system is suspended and which helps to stabilize the generated image. The gimbal's software was modified accordingly; instead of only compensating movements, the gimbal now focuses on fixed GPS coordinates.

Imaging Moving Targets

But these are not the only special features: The circular SAR is not only capable of imaging static objects, but – for the first time ever – moving targets as well. This has been shown in a series of tests in which a roundabout was imaged using circular SAR. Using single-channel, linear SAR, cars passing through the roundabout would be blurred; it would not be possible to determine their shape. A sharp image of the shape of moving objects could only be achieved if all three of the objects' speed components were known – which is usually not the case. With the circular SAR, this is different. Here, the objects' moving shadows are discernible, as well as their concrete shapes. Trucks, compact cars, and people can be clearly distinguished by this means.

The single-channel measurement can even provide height information, since different focus levels can be set: For instance, focusing on the street level will allow manhole covers, cars, etc. to be recognized. Focusing on the rooftop level, on the other hand, will blur the street, while the roofs will be depicted clearly.

A prototype of the circular SAR system has already been produced. The following steps will now aim to also create a two-channel circular SAR system. Interferometric measurements will then also become possible – to analyze how the signals of the two channels affect each other. These data can then be used to directly determine the height of the objects.

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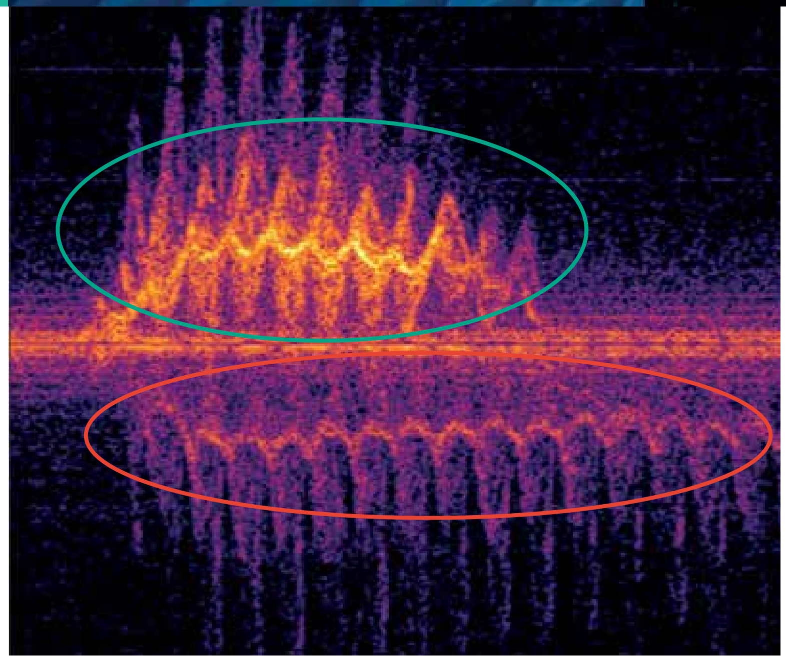

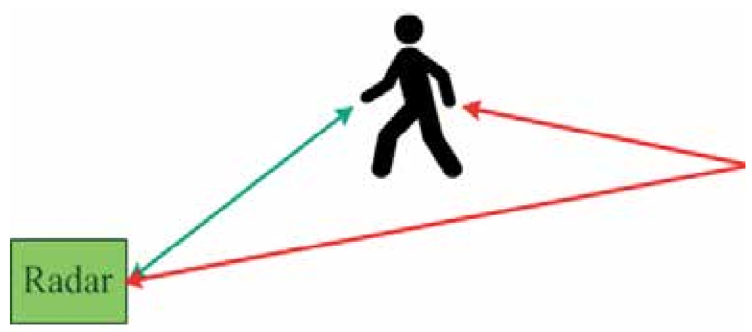

Using a MIMO radar (above), not directly reflected radar signals can also be analyzed to obtain additional information. The micro-Doppler signature (left) of a walking person (right) from the direct (green) and the indirect (red) reflection. The person is still illuminated on the indirect path after already having passed the radar.

»AROUND THE CORNER« RADAR: INDIRECT LOCALIZATION OF OBJECTS

Houses are not transparent for radar signals since the signals are reflected on the walls. However, multipath signals – which return to the detector not directly but through multiple reflections – can be used to virtually look around the corner. This makes it possible to obtain additional information which could otherwise not be captured by radar.

House walls are like mirrors for radar systems: They reflect and return the emitted signal, obstructing the view behind the buildings. Thus, in heavily urbanized areas, i.e. in cities, the signal is quickly shaded by house walls. You cannot see much. The same is true for certain object shapes: They do not return the echo back into the direction of the original signal, but into another one – thus being invisible to radar. How can a concealed object still be detected by radar? And can such a technology also be useful to increase the information content of the measurements of the objects that are directly visible?

Multipath Signals to Obtain More Information

Fraunhofer FHR is breaking new ground in this area: The use of multipath signals – i.e. signals that are not reflected back directly by the object, but by the object and other surfaces. Up to now, the idea has been to eliminate these, because they can cause interferences with the signal. But we can actually put them to use. The approach: If we use multiple transmitting antennas and multiple receiving antennas – i.e. antenna arrays – and if the signals are continuously being reflected in a zigzag course in an urban canyon, for example, we would able to look »around the corner«. The challenge in the process: Based on the signals received, we have to be able to identify whether these signals have been reflected directly or whether they reached the receiving antenna via another path.

Fraunhofer FHR uses a multiple-input multiple-output radar, MIMO in short. This radar consists of individual antennas sending different transmission signals, which allows the echoes to be associated with the respective transmitting antennas. In doing so, the direction from which the system receives the signals is different from the one it sends them in – this makes it possible to eliminate the direct signals. Each antenna sends out a signal that illuminates a very large area, while the receiving antennas also receive an echo from different directions. The direction in which the respective antenna is to point is only set in the computer afterwards. In short: The radar lobes can be set digitally afterwards. In this way, a type of matrix can be created that plots the different directions of transmitting and receiving antennas against each other. The result is high-dimensional: Frequently there are up to five dimensions. Two-dimensional images can be cut out of these dimensions as desired. Examples of these dimensions include the transmitting direction, the distance of an object or the signal's transit time. Direct signals with identical transmission and return paths through the urban canyon are not yet recognized. Polarimetric signals could be interesting here – in the long run, these could be used to identify whether the signal has gone through an even or an uneven number of reflections. Fraunhofer FHR developed this entire technology – from the hardware up to the signal processing. This involved answering questions both about the antenna arrangement and the array design as well as about data processing. For instance, what possibilities do we have to separate the signals?

Proof of Concept Completed Successfully

First measurements have already been completed: Two whiteboards were used as reflective surfaces. The signal was reflected from the first whiteboard to the second and from there back to the receiving antenna. In an additional experiment, one of the whiteboards was replaced by a person. The signals reflected directly by the person and those reflected by the person via the whiteboard back to the receiving antenna were compared. The signals were separated successfully. A next step will involve experiments with concealed objects. The system is of particular interest for the classification of objects: The more information is available for this, the better the classification that can be achieved.

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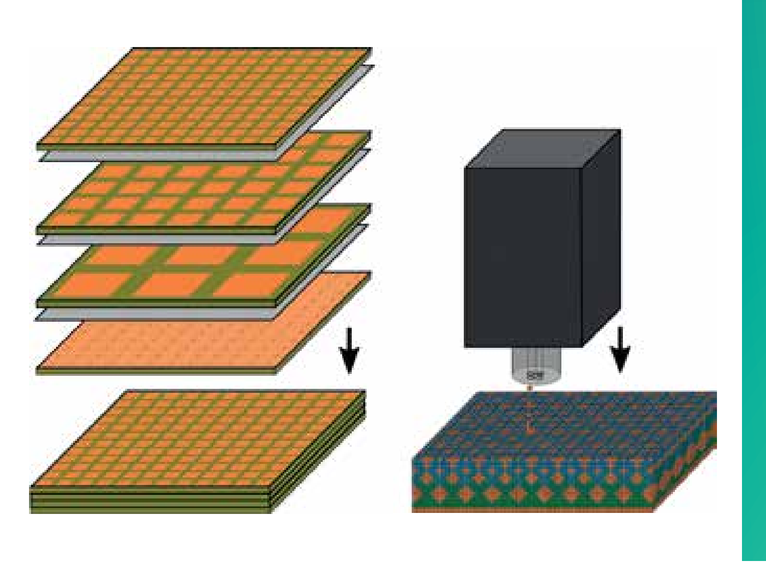
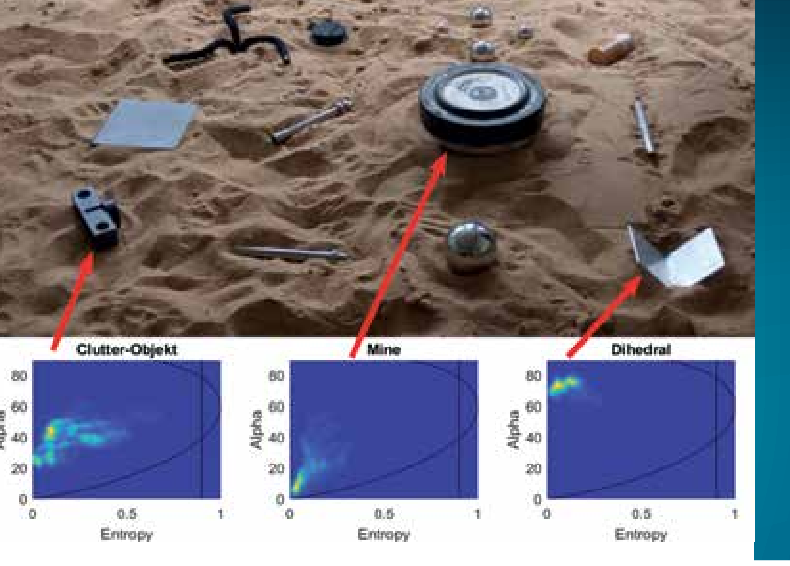
On the left: production of a broadband HF structure using conventional production processes (multi-layered printed circuit board). On the right: concept for the direct 3D printing of complex structures with new degrees of freedom in terms of material selection and geometry.





Test field with different targets to measure polarimetric GPR data (above). Results of an entropy alpha decomposition for the measured data of the targets concealed in the test field (below).

3D PRINTED MULTIMODAL ANTENNAS

How good of a resolution a radar system has is primarily determined by the radar system's bandwidth. Conventional antenna manufacturing processes, however, are maxed out when it comes to the bandwidth. In contrast, 3D printed antennas promise a higher bandwidth and, with this, an improved resolution. In addition, broadband antennas make it possible to combine the apertures of different systems.

Fighter jets, drones, and frigates have one thing in common: Numerous different systems are installed on them, each with its own antenna and there are up to 150 antennas on some frigates. On the one hand, this can make things quite tight and on the other hand, the antennas influence each other. If antennas with a higher bandwidth could be used, it would be possible to combine several antennas. A higher bandwidth is desirable for other reasons as well: For radar, the bandwidth plays a key role in determining the resolution and for communication applications, it determines the channel capacity. Multimodal antennas, i.e. a combination of antennas, offer a solution. The catch here is this: They are hard to produce using conventional manufacturing processes such as circuit boards since they seem to have reached their limit in terms of producible bandwidth.

3D Printing Allows an Improved Utilization of the Volume – Thus Allowing Potentially for Higher Bandwidths

Therefore, Fraunhofer FHR is breaking new ground and betting on 3D printing for the production of multimodal antennas. In qualitative terms, it is a known fact that a certain volume has a fixed bandwidth limit. In other words: the larger the antenna, the larger the possible bandwidth. But how can we make better use of the existing volume and achieve the highest possible bandwidth for small antennas as well? This is where 3D printing comes into play: Since we are dealing with the monolithic area – in contrast to circuit boards – it is possible to directly use the height and thus obtain higher bandwidths. This provides a better variation of the material parameters. While for simple printing processes, the same material is used for each print, the effective material parameters can be set, e. g. using targeted air inclusions. A stable process is still missing: The printing quality has to be good in the millimeter range as well, and the suitable material is also needed. The available materials are not characterized for this purpose. Fraunhofer FHR is characterizing purchasable materials for the high frequency area, optimizing them for this where appropriate.

In the long term, 3D printing will not only allow for different antennas to be combined but also for the antenna and the feeding network from which it obtains its energy. Conformal antennas, such as the ones integrated in an aircraft fuselage, can also be produced very well using 3D printing – the required curvature can be achieved directly with the print.

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HOW TO DETECT ALL TYPES OF MINES AND STAY SAFE WHILE DOING SO...

Being able to look into the ground is very convenient – especially when this involves clearing minefields of their dangerous cargo. This is exactly what a ground-penetrating radar does. Fraunhofer FHR has now developed an experimental, polarimetric antenna array including analysis algorithms. The special feature: The antenna array allows for a grid width of only ten centimeters.

Clearing minefields is still a dangerous affair. Metal detectors only help with the nerve-racking search to a certain degree because many mines and improvised explosive traps nowadays consist of plastic. Therefore, a far better option to detect these explosive threats is ground-penetrating radar, GPR in short: GPR makes it possible to detect targets made of plastic or mixed materials as well as metal. The corresponding polarimetric antennas have now been developed and set up at Fraunhofer FHR, along with the algorithms for the target classification.

Compact Polarimetric Antennas

The principle: Numerous polarimetric antennas are installed one next to the other in an antenna array at the front of a vehicle where they illuminate the terrain below, while the algorithms immediately analyze the captured data. After all, the information to tell us whether there is a target in the ground in front of a vehicle has to be known before the vehicle reaches that spot. But what exactly is a polarimetric antenna and why do we need it? Many GPR systems operate with only one polarization of the emitted and received electromagnetic fields, permanently aligned with the walking or driving direction. A polarimetric antenna also has a second polarization, aligned perpendicular to the first one. Therefore, the measurement provides more information and an improved assessment. This type of antenna already exists, but the remarkable feature of this one is its compact design – a bistatic, polarimetric antenna pair with one transmitting and one receiving antenna each only takes up twice the grid size, i.e. twenty centimeters. This way, the antennas can be arranged close together side by side to quickly and effectively examine the ground along the entire width of the vehicle.

Algorithms for Classification

Another focus is the development of algorithms: These are to first analyze the material and the orientation of the target and then, in the future, proceed to also classify the target. Is this a rock, a mine, or a harmless plastic bag? A corresponding database with comparative data is required to be able to make such a classification, so for this purpose, the polarimetric antennas were used to examine a test field containing a variety of buried objects.

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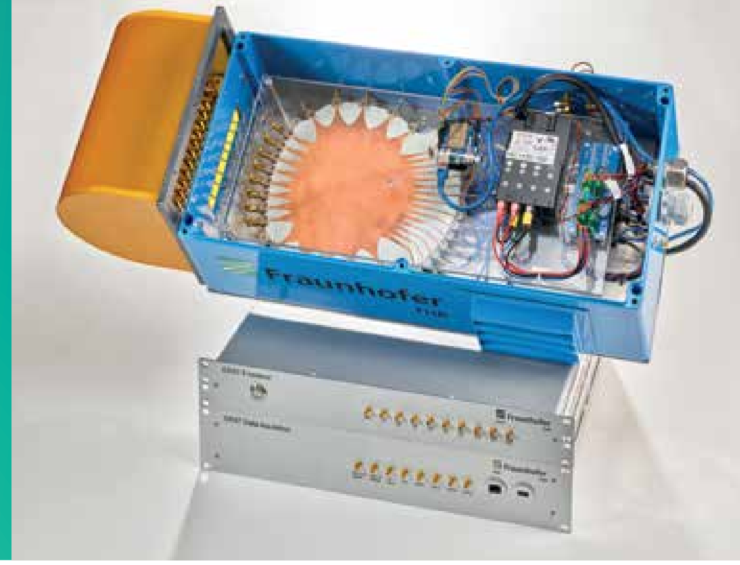
Central part of a SAR image captured during the measuring campaign in England.



The ERAT receiving system developed at Fraunhofer makes up a core component of the MFRFS system PALES.

NATO MEASURING CAMPAIGN WITH THE PARTICIPATION OF FRAUNHOFER FHR RADAR SYSTEMS

Is it worth it to examine the same scenario using radar systems with different frequencies? Could this make it possible to distinguish dummies from weapons, for example? And what additional information can be obtained by capturing the same object from different angles? Fraunhofer FHR participated in a NATO measuring campaign that set out to answer these questions.

In July and August 2019, the microlite aircraft »Delphin« circled a military training area in England. The special thing was: The training area was examined from lofty heights using alternating Fraunhofer FHR radar systems mounted under the aircraft's wings. This was part of the Multidimensional Radar Imaging measuring campaign carried out by the NATO Research Group SET-250 with the participation of Italy, Poland, the United Kingdom, South Africa, Switzerland, the Netherlands, Australia, and Germany. In the summer, particularly the radar systems from England, the Netherlands and the German Fraunhofer Institute FHR were brought together.

What Is the Added Value Provided by Multisensory Radar?

The question that has to be answered by the measuring campaign and the upcoming follow-up research: What is the added value provided by multisensors and flexible imaging geometries – i.e. measurements with different frequencies, polarizations, viewing angles, and resolutions? Military radar systems usually operate in the ten gigahertz range. But different materials have different reflection properties at different frequencies: Thus, it is possible for an object to be transparent for a beam with a certain frequency, but visible when captured with another frequency. There should be a benefit from viewing a target using radar signals with different frequencies. It is expected that this will make it possible to better expose dummies – for example empty plastic tubes fitted to tanks instead of weapons. A kind of 3D effect should also be achievable when examining an object from different sides to then fuse the pictures.

Radar Systems with Frequencies from 1 to 94 Gigahertz

While the Dutch L-band radar operated at 1 to 2 gigahertz, the frequency of the British X-band radar was approximately 10 gigahertz. The two Fraunhofer FHR systems operated at 34 and 94 gigahertz respectively: The Ka-band system PAMIR-Ka features a high bandwidth, and in the long run, the antenna direction should be streerable in two directions – this will make it possible to look into the desired direction even when the aircraft is drifting. In contrast, the special feature of the MIRANDA-94 system is its high frequency of 94 gigahertz. Moreover, the system's main components were produced in Germany, mainly at Fraunhofer IAF in Freiburg. A next step will now involve analyzing the acquired data together and then combining them.

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HUNDRED BECOMES ONE: COMBINING ANTENNAS ON FRIGATES & CO.

Quite frequently, the shape of an aircraft can already be recognized without its outer skin: based on the distribution of its tightly packed antennas alone. That is because, to date, each function requires its own antenna system. Thus, the available space is completely exhausted. At Fraunhofer FHR, different approaches are being developed to minimize this antenna forest and to resolve the issues associated with this.

Far more than a hundred sensor systems and antennas are clustered together on military platforms such as aircraft, ships, and frigates – occupying even the smallest of spaces. This causes problems, not only due to lack of space: The antennas interfere with each other.

One Antenna for All Applications?

That is why Fraunhofer FHR is addressing the following questions: What is the most intelligent way to arrange the antennas? Can multiple functions be covered by one antenna – i.e. can antennas be combined? This is all the more challenging because the different systems often use the same frequencies: For instance, passive radar operates in the lower frequency range, just like communication. Especially in places where space is even more limited – for example in aircraft – it would make sense to be able use a single antenna for all applications: whether for communication, radar, electronic reconnaissance, or electronic countermeasures. The bandwidth of the antennas has to be as broad as possible for this, meaning the antennas have to cover many different frequencies and, in electronic reconnaissance, the entire area. Two approaches are being pursued at Fraunhofer FHR: On one hand it is possible to take out individual antennas from group antennas consisting of over a thousand individual ones to use them for other issues; or the entire group antenna is used, while the area is simultaneously covered by a multi-lobe system.

The project also addresses the following question: How can the same frequency be used for transmitting and receiving antennas? This can be achieved using either pulsed signals – where the antenna sends out a short signal, waits for the echo, and then sends out another signal, thus alternating between transmitting and receiving. Or through continuous signals, where calculations are used to eliminate the transmitted signal from the received signal so that the two can be distinguished. The first demonstrators have already been set up: They are currently capable of alternating between different tasks, while further research is still required for simultaneous operation. These approaches are also of interest for the civil sector: For example for autonomous cars, mobile phone manufacturers, or network operators, because if signals can be sent and received with the same frequency, network operators could service twice as many users with their frequencies.

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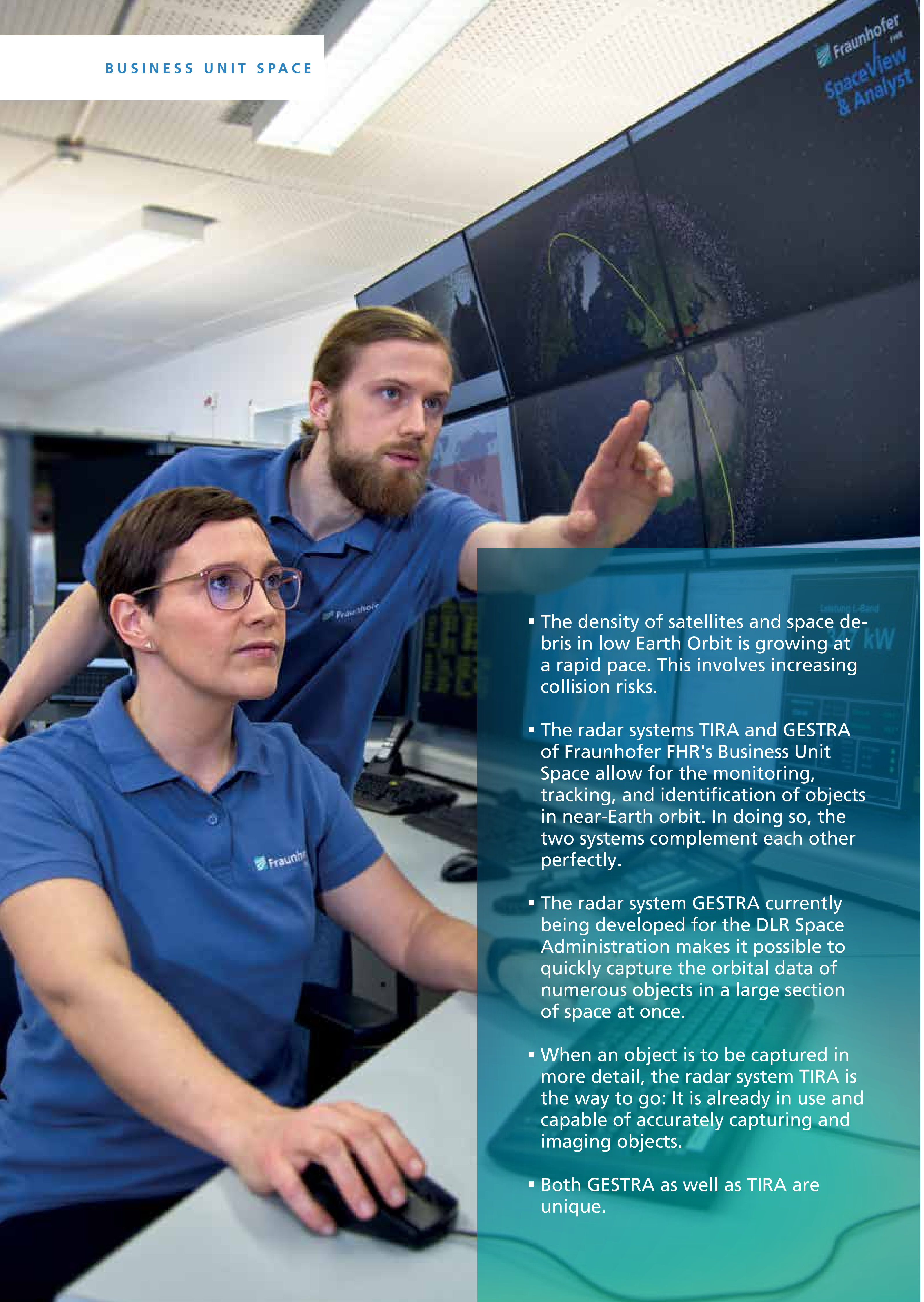

- The density of satellites and space debris in low Earth Orbit is growing at a rapid pace. This involves increasing collision risks.
- The radar systems TIRA and GESTRA of Fraunhofer FHR's Business Unit Space allow for the monitoring, tracking, and identification of objects in near-Earth orbit. In doing so, the two systems complement each other perfectly.
- The radar system GESTRA currently being developed for the DLR Space Administration makes it possible to quickly capture the orbital data of numerous objects in a large section of space at once.
- When an object is to be captured in more detail, the radar system TIRA is the way to go: It is already in use and capable of accurately capturing and imaging objects.
- Both GESTRA as well as TIRA are unique.

ACCURATELY DETERMINING THE POSITION OF OBJECTS IN SPACE

There is a high traffic density not only on highways and federal roads in urban areas. Near-Earth space is also congested and, in some areas, overcrowded. It is packed with active satellites as well space debris – and this density is growing at a rapid pace. Just like on the road, this situation involves increasing risks. Collisions can destroy satellites and compromise infrastructure that is important to society. For this reason, it is crucial to detect, monitor and track space objects: If the orbiting objects are always in view, countermeasures can be initiated in time if danger is imminent, for instance evasive maneuvers for satellites. Space Situational Awareness, SSA in short – i.e. the detection, identification and position determination of space objects – is a research topic that is becoming increasingly important, both in the European as well as in the international context. This research field is gaining importance for military purposes as well. For example, there has been an increase in suspicious maneuvers with spy satellites approaching other satellites or even docking onto them. New space powers like India and China are testing anti-satellite missiles to exhibit their capabilities. US President Trump recently established the Space Force as a separate military branch due to the increasing threat in and from space. And France has announced plans for the development of space-based laser weapons for defense purposes.

GESTRA and TIRA: Hand in Hand

The radar systems that Fraunhofer FHR's Business Unit Space researches and develops are ideal for the monitoring, observation, and identification of objects in near-Earth space. In this respect, the two radar systems TIRA and GESTRA complement each other perfectly. The radar system GESTRA currently being developed for the DLR Space Administration allows for the continuous monitoring of large areas of space – it is capable of simultaneously determining the orbital data of a large number of objects. For example, GESTRA also makes it possible to determine the height of the objects as well as their inclination – the degrees between the Earth's equator and the orbit. Another special feature: GESTRA combines phased array antennas, mechanical mobility of the radar units in three axes, and the mobility of the entire system. Thus, GESTRA can be deployed at any given site and allows for the creation of a radar system network for space surveillance.

If, however, one wants to capture a certain satellite or any other space object in more detail, the system of choice is TIRA. TIRA is already in use and provides a significantly more accurate capturing and imaging of satellites – even delivering information about the satellite itself. For example, if a satellite is not working, TIRA can help find out if this might be due to a solar panel that failed to unfold correctly. The possibility of obtaining extremely sharp images of space objects with TIRA is unique in all of Europa – the system has already supported a multitude of missions.

To date, the focus of the Business Unit Space was on the described surveillance and tracking of space objects. Additional fields of work are set to be added in the future. On one hand, the plan is to complement Earth-based SSA sensors with a space-based radar. The radar system observing the space objects will then not be located on Earth, but on a satellite in orbit. On the other hand, the portfolio is to be expanded to include other research topics. Examples are active array antenna technologies for communications satellites, SAR (synthetic aperture radar) technology for Earth observation satellites and satellite-based microwave radiometers for climate and environmental research. Thus, in the future, the Business Unit Space will be even more diversified than now – this wealth of expertise of Fraunhofer FHR will then benefit other fields of space research as well.

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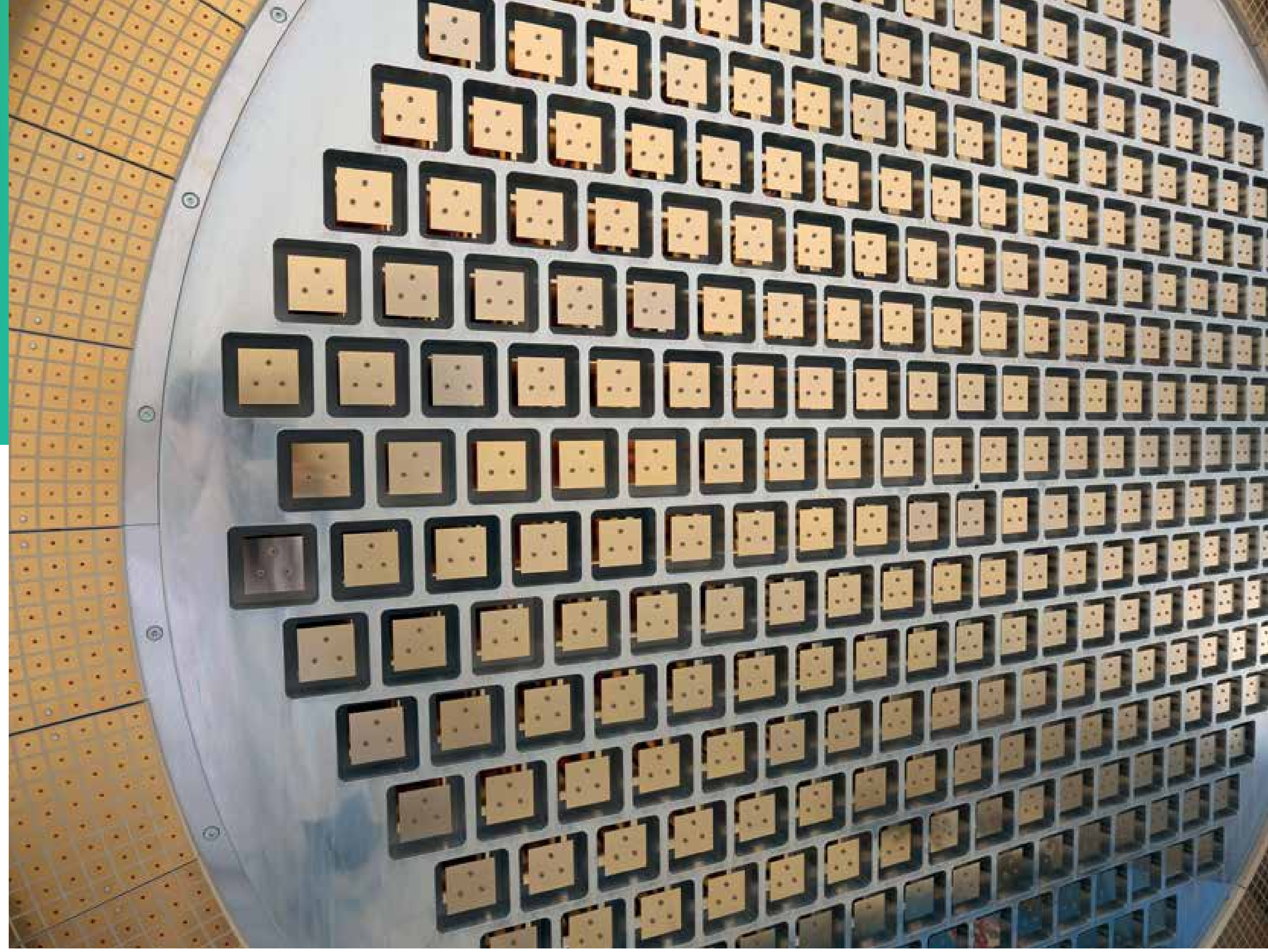

Phased array antenna of the GESTRA transmitter and receiver.

GESTRA: LOW EARTH ORBIT ALWAYS »IN SIGHT«

In order to monitor low Earth orbit and know which objects are moving around there, a phased array radar with high beam agility is required. Fraunhofer FHR is building such a radar for the Federal Ministry of Economics. In September 2020, the partially mobile space surveillance radar GESTRA will be handed over to the German Aerospace Center (DLR).

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What is flying around Low Earth Orbit, LEO in short, and where? This question is not only an interesting in itself, it is also relevant for our daily lives. LEO is where the satellites travel along their orbits, providing us with information – whether for navigation systems, for critical infrastructures such as communications, stock markets etc. And this is also where significant amounts of space debris are flying around – representing an increasing danger to satellites. NASA has created a catalog – the Master Catalog - to be able to warn satellite operators in time when a piece of debris is getting dangerously close to a satellite. This catalog contains most of the flying objects in LEO. When it comes to US satellites, however, most of them cannot be found in the lists due to tactical reasons. Therefore, Germany would like to free itself from this dependency. This requires two different radar systems: One that tracks and images individual space objects – this is done by the space observation system TIRA at Fraunhofer FHR and another one that fulfills the surveillance function, i.e. that detects the different objects in a large section of space. This can only be achieved by a phased array radar with a high range and beam agility that has not been available in Germany until now.

Core Competence: Fast Space Surveillance

The Federal Ministry of Economics therefore commissioned the Fraunhofer FHR to set up such a phased array radar: from the conception and the design phase to the operational system. The design involves a quasi-monostatic system consisting of separate transmitting and receiving subsystems. The phased array antennas are each set up with a 3-axis positioner: This makes it possible to first set the surveillance area mechanically and then scan this area electronically within milliseconds. In the process, the radar beams form a type of fence that can be likened to windshield wipers. Every object that is large enough and passes through the fence will be detected. GESTRA's unique feature: It is partially mobile, meaning that it can be set at any location. In addition, it is able to very accurately determine the position of objects.

September 2020: Handover to the DLR

By now, the GESTRA system is about 90% complete. Next up will be the series acceptance of the components from Fraunhofer FHR, particularly the electronics in the transmitting and receiving antennas. In May 2020, GESTRA is to be brought to the military training area Schmidtenhöhe near Koblenz to be connected to the existing infrastructure on site. System checks for the German Aerospace Center (DLR) as the project management owner on the contract side will then follow. In September 2020, GESTRA will be handed over to the DLR as well as the Space Situational Awareness Center. The Space Situational Awareness Center will use the new radar system to create a German master catalog. If there is more interest in a specific object, it will in turn task Fraunhofer FHR with the tracking and imaging of this object using TIRA.

Since GESTRA is to be operated in Uedem in North Rhine-Westphalia – i.e. remotely – it has to be possible to check the system's »health« anytime. That is why the 34-member GESTRA team installed over 2000 sensors that can be monitored via a remote control. When all sensors give the »green« light, GESTRA can be started. The sensors also monitor the different functions during operation.

In the long run, interconnecting multiple GESTRA systems will make sense: Because if the radars are set up 300 kilometers apart from each other, they will see the objects from different angles, allowing for a more significantly accurate position determination than when using only a single radar. This is precisely the possibility provided by GESTRA's partial mobility.

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RETRIEVING SPACE DEBRIS: THE SPACE OBSERVATION RADAR TIRA CAN PROVIDE SUPPORT

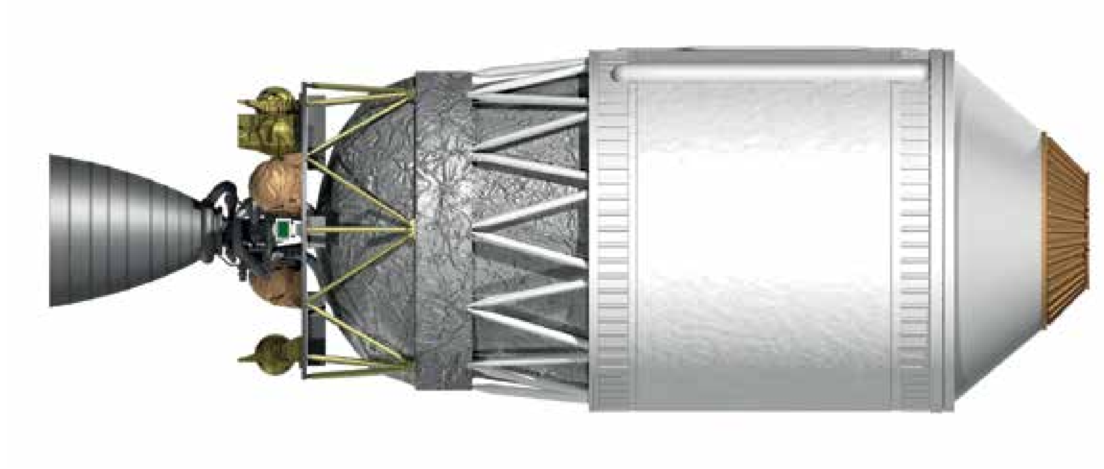
Increasingly more debris is flying around in space – a serious threat to satellites and space missions. Space agencies are therefore increasing their efforts to reduce space debris. Fraunhofer FHR's space observation radar TIRA, which is unique in all of Europe, can provide meaningful support: For instance, delivering data about how and at which speed the objects are rotating and whether they are still intact.

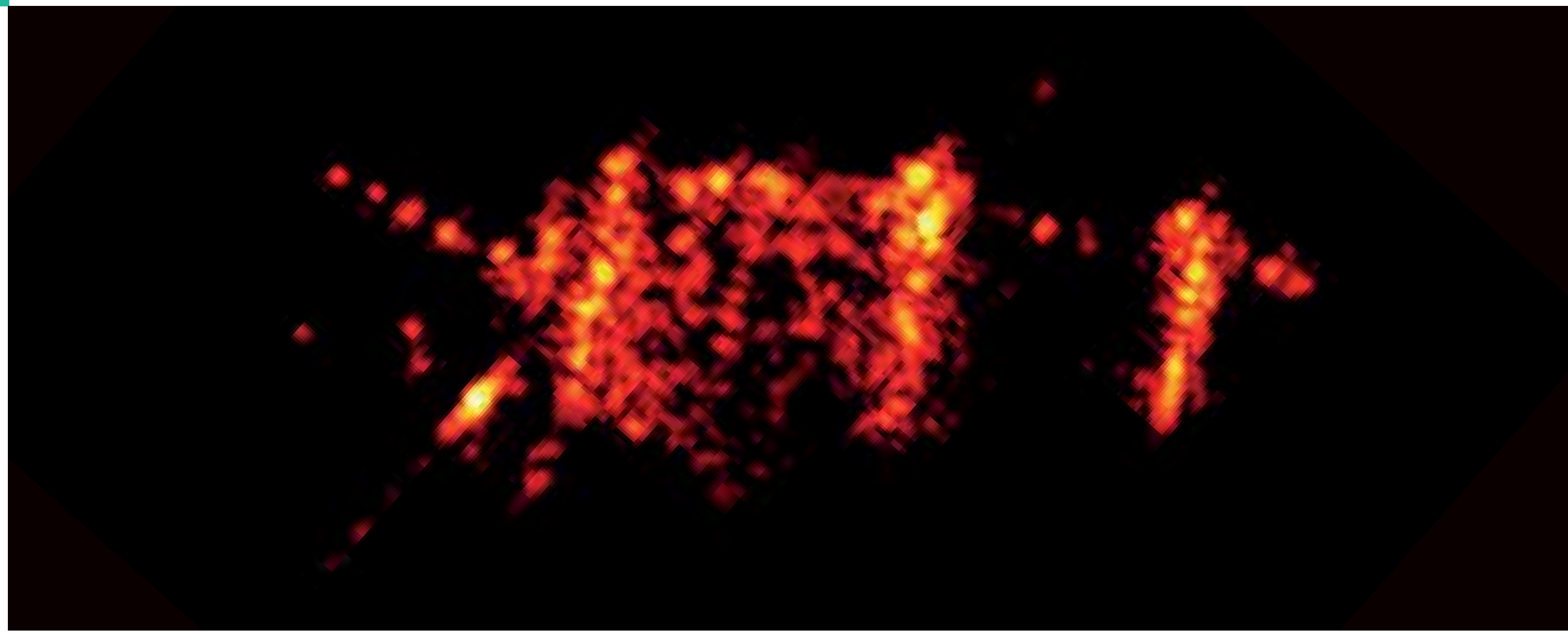
Numerous satellites travel along their orbits in space, supplying us with information – whether for navigation, communication, TV, or Earth observation. But it is not only active satellites that are flying around there: The majority of all objects in near-Earth space are already past their service life and with and with a tendency to increase in number, since after all, new debris is being added with each rocket launch. This is especially problematic for rocket stages. Their tanks frequently still contain some fuel, which time and again leads to explosions. Such an explosion triggers a cascade effect: Instead of a larger piece, a number of smaller fragments are now floating around in the near-Earth space – increasing the probability of a satellite being hit and damaged or even destroyed by such an object. Because even these small objects represent a danger: Satellite failures occur time and again, for example because fragments have perforated the solar panels.

Even though near-Earth space is large, satellites do orbit Earth on specific paths and the capacities of some of these paths are already exhausted today. Space agencies are therefore undertaking first attempts to retrieve space debris. ESA, for instance, is planning its first test mission for 2025; it will involve retrieving an adapter that once coupled a rocket upper stage and its payload. The aim, both during the preparations as well as during the mission, is to obtain as much information about an object as possible: How fast is it rotating? In which direction? What is its orientation in space? What is its condition?

The Space Observation Radar TIRA: Tracking and Imaging Rocket Stages

With its space observation radar TIRA, short for Tracking and Imaging Radar, Fraunhofer FHR is able to deliver the data necessary for these missions and support both their planning and execution. With its capacity to observe objects in space, TIRA is unique in Europe – the system is capable of detecting objects the size of only two centimeters from a distance of a thousand kilometers. Fraunhofer is already providing mission support services with TIRA today. On a national level for the German Space Situational Awareness Center in Uedem and on an international level for ESA, for example. One of the tasks Fraunhofer FHR was commissioned with in 2019 involved the damage analysis for an upper stage of a Japanese rocket. In order for the necessary image to be as precise as possible, the rocket stage's rotation speed must be known as accurately as possible. So it has to be determined exactly how fast it is rotating and in which direction(s). Since it can rotate around several axes at the same time, the motion can be very complex. TIRA typically observes the object during its passage for eight to twelve minutes from different angles. At Fraunhofer FHR, algorithms developed in-house are used to analyze a sequence of radar images and to then estimate the rotation speed on this basis. In the process, a 3D model matching the object's dimensions is created based on the radar images. This 3D model is then aligned using a sequence of radar images. If the motion of the 3D model match those of the object in the image sequence, the speeds were chosen correctly. If not, readjustments must be made in an iterative process.





Analysis of a Japanese H-IIA rocket upper stage.

Outlook

Space debris will continue to increase – which will also increase the risk of active satellites being damaged by fragments. A precise picture of the situation as well as retrieving and preventing space debris will be relevant topics in the future. With TIRA, Fraunhofer FHR is in a position to provide support in all three areas. For instance, damage analyses that allow for assessments concerning the fragmentation of an object contribute to the picture of the situation, while condition and rotation analyses of objects can help with the retrieval by answering the question as to which method is best suited for the mission: a net or a gripper? As far as prevention is concerned, the activation of a braking sail can be verified.

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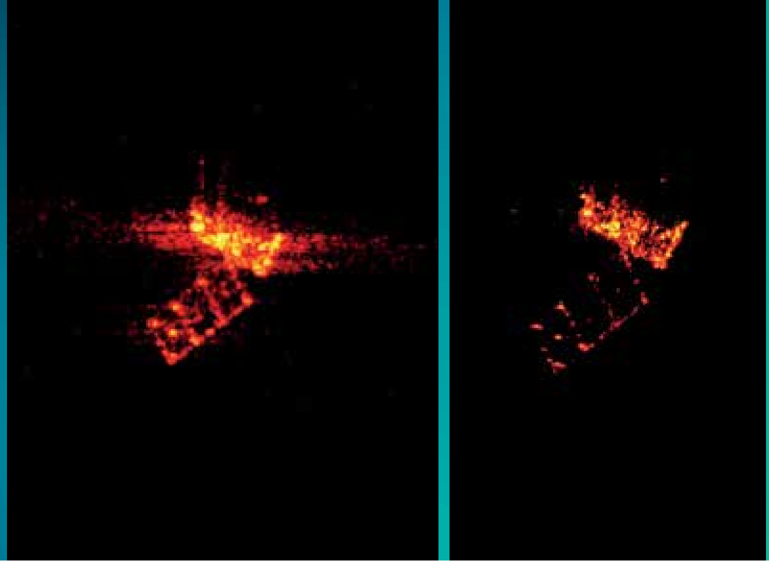

ISAR image after conventional processing (left).
ISAR image after innovative CS processing (right).

SHARPER ISAR IMAGES OF SATELLITES AND OTHER SPACE OBJECTS

The space observation system TIRA consists of a tracking radar and an imaging radar. For the imaging radar, Fraunhofer FHR is continuously developing innovative methods to improve the processing of the obtained radar data as well as the quality of the images because this allows for significantly more reliable assessments of the objects.

If the solar sail of a satellite is bent, it will get »dark« – it lacks the energy to send a signal to Earth. So questions like the following arise, not only for reconnaissance purposes: Are the satellites intact? Was there a collision? Are parts missing? Answering these and similar questions about satellites is one of the tasks of the space observation radar TIRA. That is because radar has a decisive advantage over optical systems: The systems can be employed day and night and in any weather. However, while optical systems provide an immediate image, radar provides raw data that have to be processed first. The following applies here: The better the signal processing, the more insights the image will provide. As such, the quality of the radar image can be increased by the processing.

Improved Imaging Quality

Improving the processing of the TIRA radar data to obtain more accurate information about satellites or other Earth-orbiting objects is one of Fraunhofer FHR's central tasks. The imaging of space objects with the imaging radar of the TIRA system is based on the ISA¬R, which is short for inverse synthetic aperture radar: Here, the radar set up is stationary, while the object rotates around the radar. In the process, the antenna rotates to track the object along its orbit. The radar continuously sends pulses, recording the reflected signal it receives for each pulse – this makes it possible to determine the object's range profile. Based on the change of the range profiles over time, we then carry out a spectral analysis to calculate a 2D image of the object. For ISAR, data processing is particularly challenging since the forward and rotary motion of a satellite are generally not accurately known. How fast is a specific spot on the satellite rotating? And how is the satellite itself moving? If you want to obtain a sharp image, both questions will have to be answered very accurately. The stabilization condition can be assessed based on the satellite's proper motion. Is it wobbling, for example.

A new technique was developed at Fraunhofer FHR – based on compressive sensing (CS) – to be able to process and obtain an even sharper image. This technique provides a better correction of the translational motion, combining this with a spectral extrapolation to increase the quality of the processed radar images.

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The combination of both radar systems and new complex mathematical procedures improves the accuracy of the space observation radar TIRA's distance measurement by a factor of 100.

SPACE DEBRIS UNDER THE SPOTLIGHT: HIGH-PRECISION ORBIT DETERMINATION WITH TIRA

Is a piece of space debris threatening to collide with a satellite? This question is essential for satellite operators. The more accurately they know the orbits of these pieces, the fewer evasive maneuvers are required for the satellite – and the longer the satellite can be used. The space observation radar TIRA is capable of very accurately measuring the orbits of these objects.

Internet, communications, navigation systems – a major part of our information infrastructure depends on satellites. However, these are constantly exposed to danger in space: If, for example, a screw with a size of one centimeter was to crash into a satellite, this would have the destructive effect of a hand grenade. This is due to the high relative speed between space objects: up to 15 km/s for objects in low Earth orbits.

There are approximately 750,000 objects in near-Earth orbits that represent a potential danger for active satellites. Less than 30,000 of these objects are continuously being monitored by the US Space Surveillance Network (SSN), with their orbits being continuously updated. In case of an imminent collision, the satellite operator usually requests additional observations. When the probability of a collision is high, evasive maneuvers will be executed. But this requires a lot of fuel – if the satellite has to do this frequently, its lifetime is reduced, so this involves high costs.

High-Precision Orbit Measurements of Space Objects

Fraunhofer FHR's space observation radar TIRA combines a target tracking radar and an imaging radar with a highly agile 34-meter parabolic antenna. Usually, only the target tracking radar is used to determine the orbit of space objects. A new method has now been developed in the EU project EUSST to measure these objects even more accurately. This was achieved by fusing the data of TIRA's two radars using highly complex mathematical methods. The proof of concept has already been provided by observing reference satellites in a joint measuring campaign together with the Space Situational Awareness Center. The data obtained in this manner by TIRA were compared to highly accurate ephemerides. In the process, the distance measurement was improved by a factor of about 100.

The aim until the end of the project, i. e. until the end of 2021, is to refine these mathematical methods. An improved atmospheric model is also necessary to compensate wave propagation effects more accurately. By the end of the project duration, TIRA will have a new experimental mode that can then be used for special contract measurements.

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- The attacks on the World Trade Center on September 11, 2001 led to numerous national and international research programs aiming to protect the civilian population in times of peace.
- Security research is based on three major pillars: Protection of people, protection of critical infrastructures, and protection against crime and terrorism.
- Radar offers a number of ways to increase civil security for all three of these pillars.
- For example, drones combined with radar technology are capable of locating signs of life of people in smoke-filled buildings or under debris.

CIVIL SECURITY: WIDE-RANGING SUPPORT BY RADAR

On September 11, 2001, the attack on the World Trade Center spread fear and terror throughout the world: After all, it was the first terrorist attack of this scale on a civilian target. Further attacks followed in Madrid in 2004 and in London in 2005. Research responded: While previously there had not been any security research for the civilian sector, in the aftermath of the attack on the twin towers, numerous national and international research programs were created to address the protection of the civilian population in times of peace. One example for such a program is the German federal government's security research program »Research for Civil Security«, which is currently heading into its third round. In general, security research is based on three major pillars. First: The protection of people – whether at big events, train stations, or airports – as well as their rescue, for instance in natural disasters, epidemics, attacks, or similar. Second: The protection of critical infrastructure. This includes airports, train stations, waterways, and bridges as well as energy and water supply and communications. Third: The protection against crime and terrorism. For instance, how can we deal with the fact that more and more people on the streets carry knives and even use them in trivial disputes? There are about a dozen knife attacks – per day! in Berlin alone. Radar offers a number of ways to increase civil security for all three of these pillars and Fraunhofer FHR's Business Unit Security is a competent point of contact.

Protecting and Rescuing People: Unmanned Systems with Radar Sensors

In a disaster, it is often difficult or even impossible for the emergency forces to quickly get a precise picture of the situation. For instance, in the event of a fire it is extremely dangerous to enter a burning building to search for people. Drones combined with radar technology can help. Drones can fly into smoke-filled buildings and locate signs of life or animals using integrated radar sensors. At the same time, radar sensors can ensure that the drones navigate safely through buildings without hitting any obstacles. This way, rescue missions would be significantly faster, more efficient, and safer. Radar sensors can also provide valuable services when searching for buried people by locating signs of life underneath the debris. In a next step, it would be conceivable to let drones work autonomously – this would provide further relief for human rescue workers. The Business Unit Security is already conducting research on this type of radar technology in a variety of directions. Cognitive radar goes even further, with the radar system independently setting the optimal parameters, fine-tuned to the current situation.

Protecting Critical Infrastructure: Inspection Robots Equipped with Radar Sensors

Civil security also includes discovering the smallest of cracks in power plant cooling towers, tunnel systems, bridges, or similar infrastructure. Drones and robots can take on these sometimes dangerous but also time-consuming tasks. There are two starting points for radar technology here: On the one hand, it can prevent collisions via sense and avoid. When the radar sensor detects a wall or another obstacle, the data can be sent to the drone's or the robot's control system to ensure that it avoids the obstacle. The Business Unit Security has already successfully completed the first tests. On the other hand, radar sensors offer advantages for the analysis of infrastructures – for example, they are capable of providing images exact to the millimeter and detecting cracks and damages even in dark, smoke-filled, or inaccessible environments.

Protection Against Crime

Radar systems are also very useful for the third pillar, protection against crime. For example they make it possible for security forces to detect whether people are carrying knives or other dangerous items underneath their clothing without the need for contact.

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Millimeter wave radar for perimeter surveillance at the airport.

MONITORING THE SURROUNDINGS ON THE GROUND AND IN THE AIR

When drones cross paths with departing or landing aircraft, things can become dangerous. That is why the federal government wants to protect airports better. One possibility for this is a radar system that simultaneously monitors both the ground and the airspace, while classifying the objects and determining their altitude. The system can also be used to monitor military camps and checkpoints.

About a year ago, drones shut down London's Gatwick Airport, and in May 2019, operations at Frankfurt Airport also came to a halt due to a drone sighting. The reason: When private drones come close to an airport, they can significantly jeopardize air traffic. The federal government has now made it its goal to protect airports better in the future.

Determining the Altitude of Moving and Static Objects

This could be possible using a new radar device from Fraunhofer FHR. The device is not only capable of simultaneously monitoring the ground and the airspace, but also of classifying the detected objects – for example distinguishing between a drone and a bird – and determining their position and altitude. The radar device is located on the ground and rotates around itself once every 625 milliseconds, therefore measuring in all directions. In addition, a transmitting antenna sends out radar waves with a medium frequency of 94 GHz. Two receiving antennas that are slightly tilted toward each other allow for the determination of an object's height above ground. When the drone is flying further up above, the upper receiving antenna will receive a greater signal than the one below, and the other way around. This is called an amplitude monopulse. Another advantage of the system: In contrast to other systems, it is able to detect both static as well as moving objects. Thus, it also sees the drone when it is »standing still« in the air. Since the medium frequency is 94 GHz, it is highly sensitive and capable of detecting even small structures very well.

Bird or Drone? Classifying Objects

Another special feature: The system distinguishes between different objects – for example between a drone and a bird. This is made possible by the system analyzing the signal's speed components. While a bird only moves with a few different speeds – the bird's flying speed, the fluttering of the wings, perhaps a movement of the head – the rotors of a drone move at entirely different speed. Every object has its very own speed signature through which it can be classified. This ensures protection on the ground as well, for instance in a military camp. Is that a person moving through a restricted area or only a stray fox? The radar has already been set up as an experimental system and is currently being used for research purposes.

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The compact and easy-to-operate radar device from Fraunhofer FHR reliably detects mini drones.

POLITICAL DEMONSTRATIONS? SPORTS EVENTS? DETECTING DRONES...

When a sports event is held in a stadium, you not only have to ensure the safety of athletes and spectators, but also prevent the event from being misused for political statements – for instance with a drone flying circles through the stadium with a banner. A compact, user-friendly Fraunhofer FHR radar system reliably detects the smallest of drones.

Nowadays, even amateurs can easily operate small drones. The small flying objects pose challenges to security forces and the police – as they can be used to disturb political events or make statements at sports events by pulling banners or flags. Therefore, a number of partners have come together in the ORAS project, with Fraunhofer FHR being one of them. The goal is to develop a system that reliably detects mini drones in urban environments while being easy to operate. The German Federal Office of Criminal Investigation BKA and the Baden-Wuerttemberg Police with the PTLS Pol headquarters for technology, logistics, and service are on board as associated partners and possible end users.

All-round View with the »Fence Radar«

In this respect, Fraunhofer FHR is focusing on radar – more specifically on sensors placed on the ground looking upwards, for example to monitor urban canyons. It is also possible to use the radar systems to set up a type of fence. For this purpose the sensors will have to be positioned about 70 meters apart from each other. Another partner will complement this »fence radar« with a dome radar that is positioned at a higher level – for instance on a roof – keeping an eye on the sky. Since this radar is not able to look into urban canyons, the two systems complement each other perfectly. The distinctive feature of Fraunhofer's system is mainly its compact size – no larger than a small shoebox, mounted on a simple tripod – and its easy operation. In addition, the system uses a frequency range close to 60 gigahertz, which recently became license-free for the used class. The system measures both the drone's distance from the system as well as the angle, so that a simple movement trajectory can be calculated from this data.

The radar sensor was successfully tested under real-life conditions in a measuring campaign in 2019. This was done in the Training Center »Retten und Helfen« in Moosbach, a closed down barracks with different buildings. The partners will now work on further fine tunings, and with the final demonstration set for the summer of 2020 in Moosbach. The system can also be used for other questions involving threats posed by mini drones. For instance to secure corporate development departments – when a drone flies onto company premises.

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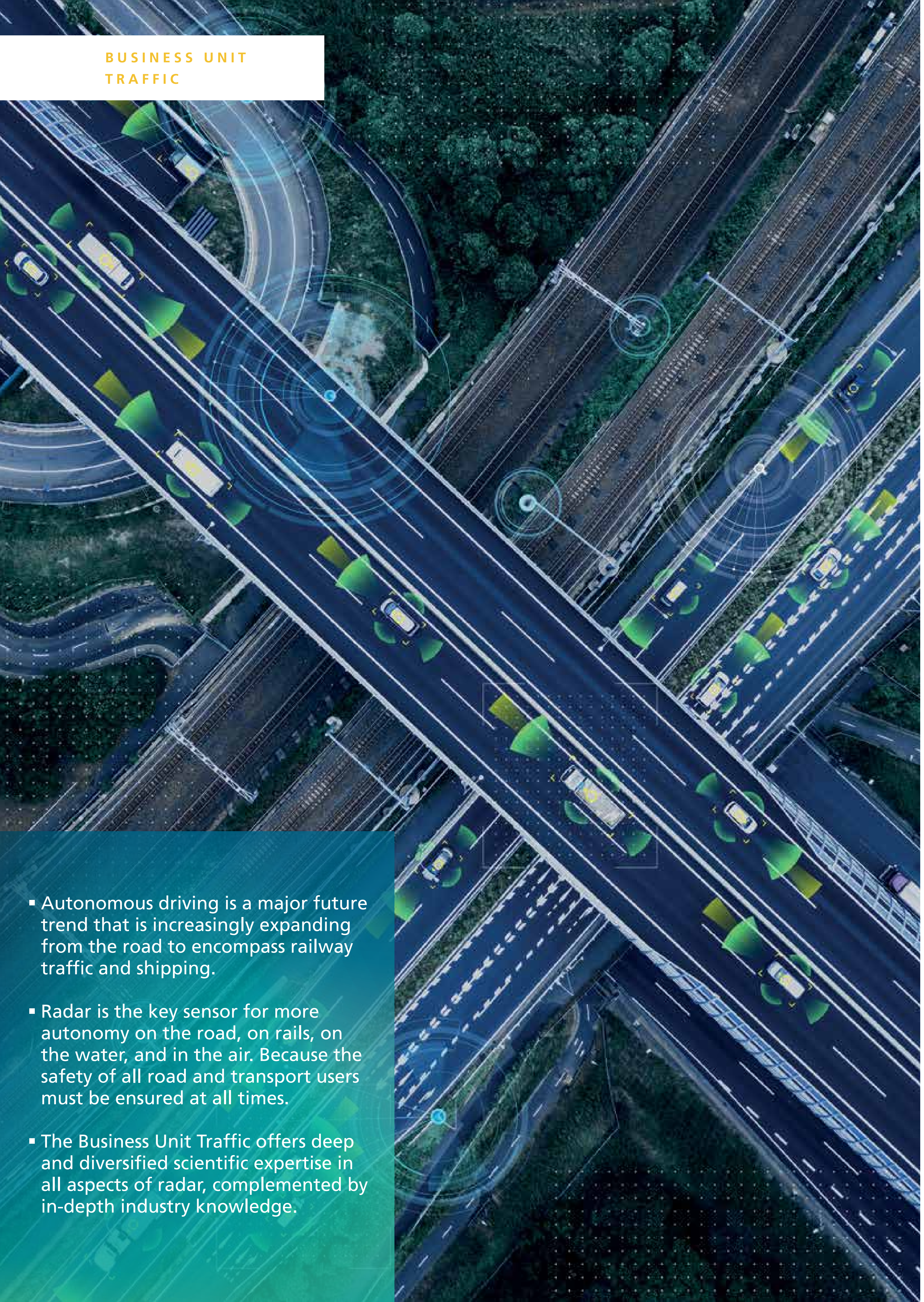

- Autonomous driving is a major future trend that is increasingly expanding from the road to encompass railway traffic and shipping.
- Radar is the key sensor for more autonomy on the road, on rails, on the water, and in the air. Because the safety of all road and transport users must be ensured at all times.
- The Business Unit Traffic offers deep and diversified scientific expertise in all aspects of radar, complemented by in-depth industry knowledge.

RADAR SYSTEMS FOR INCREASED SAFETY IN CARS, ON AIRPLANES, TRAINS, AND SHIPS

Cars that autonomously make their way through dense traffic while people comfortably lean back and read the paper – autonomous driving is a huge future trend in the traffic sector. Spurred on by the automotive sector, the trend is increasingly expanding to encompass other modes of transport as well. Whether on the road, on rails, on the water, or in the air: Safety is essential for autonomous driving. The vehicles must to be able to observe and assess the traffic around them to initiate the required responses – for instance to fully brake when a child runs onto the street. Radar sensors are ideal for this task: Because, in contrast to optical sensors, they work day and night and in any weather condition – even in dense fog. One could say: Radar is the key sensor for more autonomy on the road, on rails, on the water, and in the air.

When it comes to radar, Fraunhofer FHR's Business Unit Traffic offers deep and diversified expertise: From high frequency systems and signal processing to the classification of objects all the way to electromagnetic simulations. The business unit boasts high-quality cutting-edge technical equipment and a staff with in-depth physical knowledge. But there is more: The staff members are also very well versed in the mobility industry and extremely familiar with current challenges and issues. Thus, in the Business Unit Traffic, even challenging problems can be resolved in a beneficial way and tailored individually to the customer.

On the Road...

Nowadays radar sensors are installed in cars as a standard feature to support drivers. The Business Unit Traffic has already contributed its expertise in this area as well: Special radar antennas from Fraunhofer FHR have been installed 30 million times in 100 different vehicle types. Currently, particular focus is on the miniaturization of the systems as well as the development of conformal antennas – meaning antennas that adapt to the car's geometry for an optimal fit into the available constructed space. Further current research approaches in the Business Unit Traffic address the question of how radar waves interact with different materials. This is important, for example, when a radar sensor is to be installed behind a company logo or the bumper, while being invisible to the user. Newly developed sensors are »put through their paces« in a test environment. Our simulation software GOPOSim allows for the insertion of different moving objects such as cars, bikes, pedestrians, and dogs into the different road scenarios.

...on the Water, in the Air, and on Rails

At the moment, the business unit is heavily marked by applications in the automotive sector. But the level of autonomy is also increasing in other traffic areas – bringing about the associated requirements for the sensor technologies. For this reason, the Business Unit Traffic has also made significant contributions to the development of a number of radar sensors for shipping and aviation. An example from shipping: The innovative sea rescue system SEERAD makes it possible to locate shipwrecked persons at a distance of six kilometers with a transmission power of only 100 watts – a world record. In the aviation area, Fraunhofer FHR has developed a landing assistance system for helicopters, among others. The system assists the pilot during the landing maneuver, when visibility is reduced by stirred up dust.

As far as the activities in railway traffic are concerned, the goal is to keep developing these in the future – because there are barely any solutions available in the market yet. The Business Unit Traffic wants to close this gap. There are numerous applications for radar systems in railway traffic: For example, the sensors could analyze the track beds, detect cracks in tunnel walls, measure track widths, and address similar questions.

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Single-channel radar target simulator (above) and artistic representation of the multichannel radar target simulator currently being developed (below).

»DRIVERLESS« CARS. HOW THEY CAN SAFELY HIT THE ROAD

Many experts assume that, in the long run, cars will be driving on our roads autonomously. However, this requires the necessary safety technologies – including radar sensors. These have to be tested on several millions of kilometers of road first, an effort that is extremely hard to tackle. A radar target simulator will make these tests significantly easier and cheaper.

Modern cars today are already equipped with radar sensors, most of the time, they are installed under a company logo or in the bumper, where they provide automatic collision or distance control. For instance, a car in cruise control automatically brakes when the car ahead reduces its speed. The aim for autonomous cars is not only to support the driver, but to actually allow the driver to do something entirely different while the car is independently moving toward the destination. The radar sensors required for this, however, have to fulfill significantly stricter general conditions: Only a single error is permitted to occur in several millions of kilometers on the road. To date, these radar sensors are tested by installing them in cars to have them hit the road – a time-consuming and cost-intensive procedure.

Faster and Cheaper Tests

The virtual testing environment ATRIUM, the German acronym for »automobile testing environment for radar in-the-loop testing and measurements« aims to change this – it is being developed at Fraunhofer FHR. The tests no longer require a driver, so they can be done much faster and cheaper. In addition, a significantly greater number of scenarios can be tested, and the radar systems can be examined under realistic conditions already as they are being developed. The principle: Radar sensors emit radar signals while the car is on the road. These signals are reflected back to the radar sensor by objects in the surroundings – whether these are cars, trees, or people – which is called the echo. These echoes make it possible to calculate the distance, speed, and direction of each object. Fraunhofer FHR's radar target simulator now creates these echoes artificially: It receives the radar signals of the sensors to be tested, modifies them accordingly, and then returns them. Thus, the simulator leads the radar sensor to believe it is driving through a virtual environment, while in reality all parts are standing still in the lab. Just like in the real world, this virtual environment can contain cars, people, buildings, and similar things.

Up to 300 Echoes Are Possible

The current system is capable of generating 16 echo signals. This version was already presented at the Automotive Testing Expo Europe trade fair in Stuttgart in 2019. It consists of one transmitter and one receiver, i.e. of a single channel. Thus, the objects can be simulated along one direction, for different distances and speeds. In order to represent cars, people & co. in a realistic manner, several scattering centers are used per object. That is because in the case of a car, the bumpers, the wheels, the wheel cases, and other components each reflect the signals in their own specific way.

At the moment, the business unit is working on replacing ATRIUM's transmitting part, which has so far been built from off-the-shelf components, by an in-house design. Then, using the corresponding signal processing techniques, it should be possible to generate a significantly higher number of reflections – instead of 16 echo signals, the aim is to reach more than 100 – thus making the scenario seem even more realistic. In a third step, to be completed by the end of 2020, a number of these transmitters will be set up. Through an intelligent arrangement, they will be able generate echo signals from different directions and angles, far more than a hundred in total. In a virtual sense, this means the following: The vehicles and people will move toward or way from the system to be tested from different directions.

Workflow for the Simulations

Generating this amount of scenarios and simulation signals involves major efforts. An already functional workflow can significantly simplify this: When you input CAD models of cars and other objects as well as movement trajectories – i.e. the movement of the objects over time – into this workflow, the simulation program calculates the individual reflections that occur. An algorithm further processes this list and calculates the parameters required by the radar target simulator. Based on this workflow, a scenario catalog is currently being developed where relevant scenarios will be kept on file.

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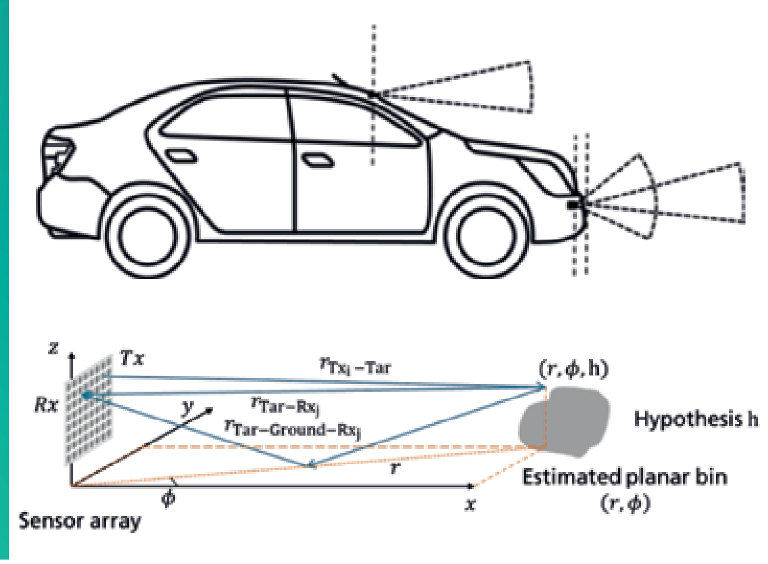
During a field test on the Baltic Sea, the system already showed what it was capable of: It located the dummy that went overboard from up to six kilometers away.



Set-up of the radar array and the multipath model to determine the height of the obstacle.

RELIABLY FINDING SHIPWRECKED PERSONS – WITH A NOVEL RADAR SYSTEM

Howling winds and heaving seas with towering waves – when a man goes overboard in a storm like this, the crew quickly loses sight of him. And conventional navigation radar does not help much either. A novel radar system, however, is capable of reliably locating drowning persons, as such providing valuable help for rescue missions. A first field test was extremely promising, but a lot of research work is still required until the system can be used routinely.

When someone goes overboard on the high seas, it is difficult for the crew to find the person among the towering waves and the ship's radar only helps to a limited degree. That is because the waves reflect the emitted radar signals similar to how a person does – so waves and people give off almost the same echo.

Locating Shipwrecked Persons from up to Six Kilometers Away

This is not the case with the new SEERAD system: It makes it possible to detect people and small rescue boats from large distances. It was developed by the Institute for Microwaves and Plasma Technology of FH Aachen University of Applied Sciences, Fraunhofer FHR, and the company Raytheon Anschütz GmbH. To do this, SEERAD uses the following trick: The radar signals are usually reflected by the water and the person in such a way that the signal's frequency remains the same. But by attaching a transponder to the life jacket that returns the signal with a different frequency, the echoes of waves and the person can be distinguished. This requires two antennas on the ship: One for the ordinary radar and a second one for the echo of the transponder. When a transponder signal reaches the ship, the rescue crew will know: Someone is in distress here. All antennas were developed at Fraunhofer FHR – the two antennas on the ship together are no larger than a ship's conventional radar antenna. In addition, the ones in the transponder are seaworthy and resist the heavy strains placed on it by the waves.

A test run in the Baltic Sea showed: The system is promising. When the dummy that went »overboard« had a passive transponder – without a battery – on his life jacket, it was possible to locate it at a distance of up to 600 meters, while an active, battery-powered transponder allowed for the »drowning« dummy to be located at a distance of six kilometers with a transmission power of only 100 watts. In comparison: Until now, so-called harmonic radar systems only scanned about a kilometer, but required a transmission power of 1000 watts to do this.

A Lot of Research Work Is Still Required

However, a lot of research work is still required to make the system useable in sea rescue missions on a routine basis. The task consists in integrating the system into the ship navigation systems, minimizing interferences, and ensuring that it permanently works under the rough conditions at sea.

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AUTONOMOUS DRIVING: DETECTING SMALL OBSTACLES AND ESTIMATING THEIR HEIGHT

If an increasing number of driverless cars is to hit the road in the long run, reliable safety technology will be needed. Recognizing obstacles on the road and along the roadside will be particularly important. This task could be solved by a radar system: It is capable of recognizing even small obstacles and determining their heights at distances from 80 to 150 meters.

A ball is rolling into the street, a dead animal is on the road, a person is crossing the street – technology has to put in a lot of effort to learn things that a human driver easily recognizes. This also applies to autonomous cars: To ensure safety, they will have to be able to reliably identify obstacles on, next to, or above the road. To date, however, such systems only detect small obstacles from distances of about 10 to 20 meters – which is too late to change lanes or fully brake.

Recognizing Objects as Small as 10 cm from up to 150 Meters Away

A radar-based solution developed by Fraunhofer FHR could provide autonomous cars with more foresight in the future: It already recognizes objects with sizes of 10 to 30 centimeters from distances of 80 to 150 meters. It can even determine their height with an accuracy of up to five centimeters. The system was developed on behalf of Audi. The principle: Small radar systems are integrated into the car from where they send out radar signals. Obstacles and the road reflect some of these signals back to the radar sensor that then analyzes them. Three clever moves make it possible to analyze small objects at large distances. First, the system uses a 2D antenna array consisting of multiple antennas positioned at different heights. Second, it analyzes both the phase as well as the amplitude along the entire examined length of the road. In simplified terms, one can say that the analysis of the amplitude helps to roughly determine the size of the object, while the phase provides for a better resolution. The third move consists of utilizing multipath information: In doing so, not only the radar signal reflected by the object itself is analyzed, but also those that are reflected first by the street and then by the object, for example. The data fusion not only allows for these different signals to be combined with each other, but also fuses information from multiple radar sensors.

Different computer simulations of realistic scenarios already showed that the system generally works and is improving the performance of conventional methods. First field tests are planned for 2020. These will involve installing a preliminary radar system in a car and checking its suitability. If the tests go well, the next step could consist of building a prototype.

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- Radar sensors are also capable of monitoring production processes where optical systems reach their limits: For example, in rolling mills, where temperatures are very high, and a lot of steam and slag is created.
- In addition, radar sensors make it possible to examine products in a non-destructive manner – whether in food inspection, for all types of plastic components, or for composites.
- The Business Unit Production offers the required expertise as well the technical equipment to turn the individual questions of industry partners into a success.

A CONSTANT EYE ON PRODUCTION PROCESSES

When something goes wrong in industrial production processes, this will very quickly lead to high costs. Thus, companies have a major interest in monitoring production processes. While some questions can be satisfactorily addressed using camera and laser systems, other production processes require sensors with capacities that go beyond those of optical systems. Radar sensors offer an ideal solution here: They are not only capable of measuring under difficult environmental conditions, for instance with limited visibility, but also of looking through dielectric materials to detect defects. Fraunhofer FHR's Business Unit Production offers the necessary expertise for all questions relating to radar.

Checking Production Processes for Metals

One interesting field of application for radar systems are rolling mills in the steel industry. Here, steel slabs with temperatures of 800 to 1,000 degrees are rolled to sheet metal. The challenge in the process: In order to separate the scale created in the production processes, the slabs are sprayed with water – the steam that rises up then complicates the use of optical measuring systems. This is different for radar systems, more precisely millimeter wave systems: They are capable of accomplishing the task extremely well, as different projects of the Business Unit Production have shown.

In general, the following applies to production processes: The earlier defects are detected, the cheaper it is to remedy them. For example, if a car door has a dent, it can be easily sorted out in the beginning. But further along the value chain, each additional production step costs hard cash. Panels designated to be made into car doors are also frequently checked visually for defects. However, a feasibility study of the Business Unit Production provided the following result: A millimeter wave sensor allows for the reliable detection of even the smallest of scratches. In the long run, this could even provide 100 percent control.

Non-destructive Testing for Food, Plastics, and Composites

Sometimes, it makes sense to not only check the products superficially, like for car doors, but to also have a look inside – without destroying the objects. Radar makes this possible as well, at least for dielectric materials. One of the applications is food testing: This involves detecting foreign matter that has accidentally gotten into the food in the production process. Radar is also a promising solution for non-destructive testing of additively manufactured components, i.e. 3D printed plastic. In addition, radar examinations offer benefits during the lifespan of a product, for instance for composite materials like the ones used for the rotor blades of wind turbines.

Looking to the Future: Smart Factories and Additive Manufacturing

What will production look like in the future? One possible vision is the smart factory, where the supply of components and production are run intelligently and autonomously. However, autonomy always starts with the sensors: This is where the Business Unit Production offers the required expertise as well as the capabilities to develop individual solutions for safety-critical aspects such as machine safety.

Additive manufacturing – where components are manufactured in a 3D printer – is another future trend. For instance, this allows for antennas to be printed or component concepts to be implemented that could not be manufactured before. Combined with high frequency technology, additive manufacturing opens up numerous new fields of application: For example, the antennas could be integrated directly into functional components of a production machine, with the components working like antennas in places where they are penetrated by the radar wave.

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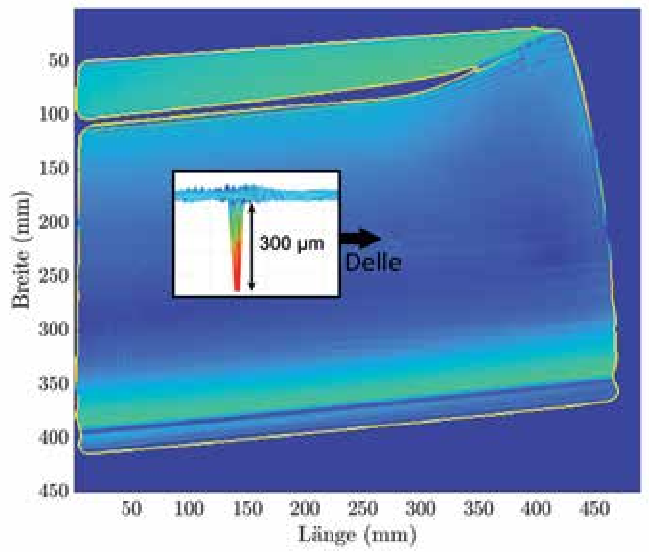
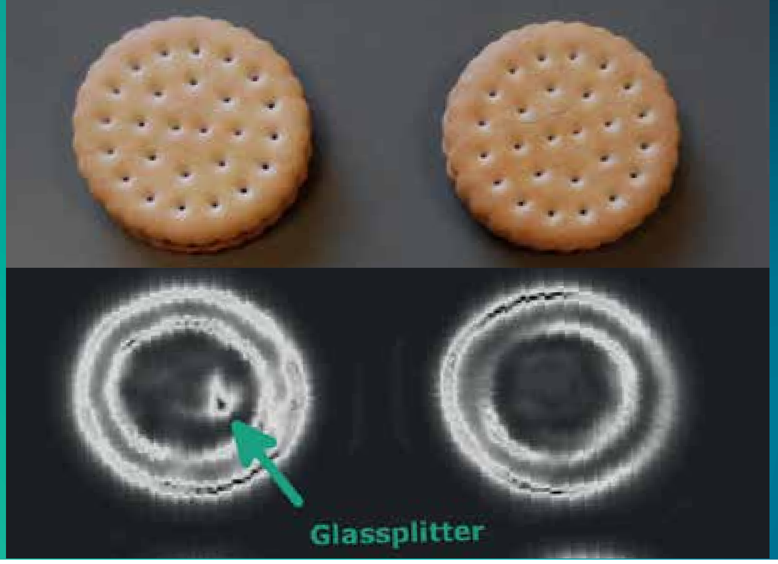


Reconstructed surface of a body panel which is inspected for defects using an 80 GHz radar.



Did something that should not be there get into the sandwich cookies (above) during production? The radar image (below) reveals a glass fragment previously placed into the chocolate cream.

QUALITY CONTROL IN PRODUCTION: RADAR-BASED SURFACE IMAGING

Did any defects occur in production? This question is hard to answer for metal components – to date, the problem has been the lack of a suitable measuring system. A new technique based on radar imaging will be able to close this gap in the future: There are no glare effects, the accuracy is in the micrometer range, and even entire steel slabs can be examined at once.

Quality control is a key concern in industrial production: For example, worn tools can quickly lead to defects in components – and thus to rejects. But particularly for metallic surfaces, such a product control is everything but easy: Optical methods cause glare effects, and interferometric systems are only able to examine small areas.

High Measurement Accuracy, Large Measurement Areas

A new radar imaging technique developed by Fraunhofer FHR combines high measurement accuracy with the possibility of examining large measurement areas – depending on the system design, even entire cars or industrial plants can be examined. The special feature of the procedure, however, is its accuracy: While conventional methods in this frequency range only achieve an accuracy of a few millimeters in a space – meaning they can make structures with a size of several millimeters visible – the new technique still manages to distinguish structures with sizes in the micrometer range. This jump in resolution was achieved by analyzing not only the magnitude of the signal but also its phase.

The sensor's algorithm is suitable for different applications. One example is the publicly funded project (NRW-Leitmarktprojekt) FiberRadar. The system is installed on a robotic arm and creates three-dimensional images of fiber composite panels as the ones used for wind turbine rotor blades or in aircraft construction. This allows for the optimization of casting processes and the fiber orientation. While infrared emitters can only inspect materials up to a depth of two centimeters, radar beams penetrate several centimeters into the materials. An ultra-wideband radar even provides information up to a depth of 20 to 30 cm; however, this is at the expense of the resolution. The imaging accuracy remains equally high in this process.

Another example of an application is the publicly funded project (NRW-Leitmarktprojekt) ASRA: A radar sensor module is to inspect steel slabs with a planned speed of up to 10 meters per second – currently, there is no technology capable of this. A modular sensor module concept is to be developed during the course of the project. It will consist of 192 transmitters and 192 receivers – up to 1,000 measurements per second are then possible.

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USING RADAR TO DETECT FOREIGN OBJECTS IN FOOD

If foreign objects such as glass fragments get into food, it poses a major risk. The established X-ray techniques mainly detect metals – glass, plastics, and wood are a challenge. Therefore, radar systems are an ideal complement: The SAMMI® prototype has already successfully detected glass fragments in sandwich cookies and missing pieces of chocolate in Advent calendars.

Time and again, food has to be recalled because glass fragments, metal chips, wood splinters or plastic parts accidently ended up inside. While manufacturers do inspect their products for these foreign objects using X-ray devices, these procedures have their difficulties with plastics, wood, and glass. Millimeter waves can close this gap and optimally complement the established X-ray procedure. Even though the radar signal cannot scan metals like tinfoil – where X-ray beams are suitable – it is capable of reliably detecting other foreign objects. In addition, it doesn't pose any health risks.

SAMMI® Recognizes Glass Fragments

A prototype called SAMMI® has been developed at Fraunhofer FHR. The system involves placing the food to be inspected on a conveyor belt and passing it through the device. The transmitting antenna rotates above the belt, the receiving antenna below. The device has a size of 40 x 40 x 30 centimeters and allows for the inspection of food with a size of up to 30 x 30 x 5 centimeters. From a purely technological standpoint, however, there is no limit. The first feasibility studies have already been completed. A glass fragment for example, was placed into the chocolate cream of a sandwich cookie and was reliably detected. An Advent calendar was also inspected successfully: The radar image clearly showed that three pieces of chocolate were missing while all others were there and correctly positioned. A next step will now aim to further improve the inspection speed and the accuracy.

The technology is not only suitable for food control. Another area for which the system offers advantages is non-destructive product testing: In the examination of an Advent calendar, for example, it can reveal whether the adhesive has been applied with sufficient thickness at the adhesive points where the calendar is held together. The system of the company Hübner Photonics is already being marketed for the inspection of letters and smaller packages under the name T-SENSE®.

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- Radar systems are getting ever smaller and cheaper, thus moving closer to humans in their application.
- One of the possibilities they offer in this area: Radar is capable of penetrating clothing to determine the breathing and the pulse rate of people – whether in the medical area, for fitness, or care for the elderly.
- In addition, radar allows for non-contact human-machine communication in environments where optical systems reach their limits.
- Radar also offers numerous advantages in the environment area, for example for efficiency improvements in agriculture.
- The Business Unit Human and Environment offers the necessary expertise in all of these areas.

RADAR: FOR HUMAN AND ENVIRONMENT

Radar technology is becoming ever smaller and cheaper – now reaching a degree of miniaturization that brings it closer to humans. But where does it make sense to the use of radar in relation to humans? Generally, everywhere where geometric and kinematic values are measured, i.e. where the shape and the movement of an object are to be analyzed.

Radar for Human

One example is checking the vital signs, i.e. breathing and the pulse rate. In this case, radar is used to measure the movement of the chest to conclude the breathing rate, while the pulse rate is deducted from the movement of the skin – and similar to the scanners at the airport, this is can be done through the clothing. One area where this is useful is for newborns in hospitals. Firstly, the small body does not offer much space for sensors, secondly family members are often irritated by seeing the small life-form immersed in cables. Further applications are possible in the areas of care for the elderly, sleep laboratories, or even fitness. As far as the signal processing is concerned, a lot of research work is still required in this attractive field. As one of Europe's leading radar institute, Fraunhofer FHR is optimally positioned for these challenges.

Radar is also well-suited for other questions involving man, such as movement analysis, be it for gait analysis in sports or in rehab. For example, together with partners, the staff in the Business Unit Human and Environment conduct research on the question of how relieving postures can be detected after an accident.

Radar for Communications

It is not only in the medical environment where radar has a lot to offer, but also in the area of communications. One field of interest is human-machine interaction. For example, many new generation smartphones are already equipped with an integrated radar sensor. The advantage: The sensor recognizes gestures even through clothing. Thus, a user can answer a call with a gesture without having to take the phone out of her jacket pocket. Gesture recognition via radar also makes sense in the area of occupational safety. Thus, you no longer need to press small buttons with thick work gloves and can instead control the machines with gestures and hand signals. This especially makes sense in areas where textile-penetrating gestures are appropriate or where the working environment contains a lot of vapor and steam, for example. The Business Unit Human and Environment is optimally positioned with its expertise to respond to this trend and to provide companies with customized support.

Radar for the Environment

The term precision farming refers to increasing the efficiency in agriculture using modern technology. Radar sensors are an ideal fit for this task: It is harmless for people, animals, and plants and can provide not only images of leaves and stems, but also the possibility of examining roots, thus enabling plant-penetrating analyses. Preliminary work is already being undertaken in this field in the Business Unit Human and Environment. In the course of climate change, the importance of weather radar and the weather forecasts bases on it is increasing as well. While these are established technologies, there is still a lot of need for improvement. Here too, the Business Unit Human and Environment is pursing many ideas – because the technological advances that were achieved in the field of radar can also be used for weather radar. Therefore, the Business Unit is planning on expanding the competencies in the weather radar area.

The environment area also includes a flashing red warning light fitted to wind turbines to warn aircraft pilots. In many regions, however, aircraft are the exception. The ParaSol radar developed in the Business Unit Human and Environment recognizes approaching aircraft, allowing the flashing light to be turned on only when needed. The system has already been approved by German Air Traffic Control.

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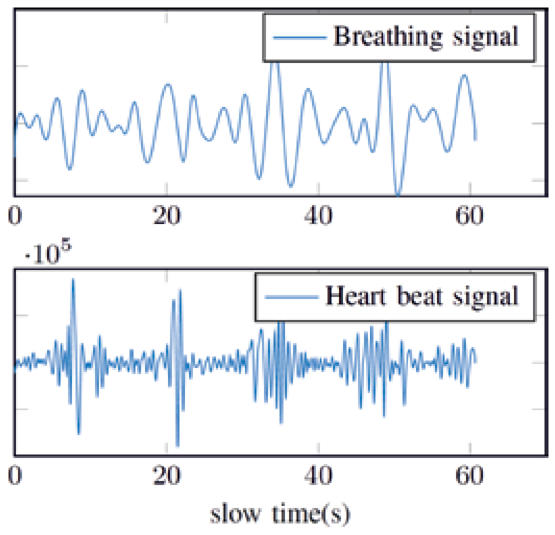

Breathing and pulse signals of a walking person measured by a MIMO radar from several meters away.

QUICKLY FINDING BURIED PEOPLE IN LARGE AREAS USING A MOBILE RADAR DEVICE

Whether in an avalanche or in collapsed buildings: Buried people must be rescued as fast as possible. Radar devices can help with the search. To date, however, they have only been able to analyze small areas for vital signs. In the long run, though, new, mobile devices can be carried by helpers or mounted on drones to cover hectare-sized areas.

Finding buried people under debris is difficult. But if you want to rescue survivors, time is critical. Radar can be a major help here: The equipment available to date, however, only allows for stationary operation. The system is set up at a certain spot from where it can check an area up to a distance of twenty to thirty meters – depending on the radar.

Pulse Measurable to Ninety-Nine Percent

A technology developed by Fraunhofer FHR can significantly increase the reach of these radar devices. This is made possible by a mobile radar device. In the future, rescue forces could carry this across a field of debris, or a drone equipped with the radar device could fly across the scene of the accident. This way, even hectare-sized areas could be searched effectively and quickly. In doing so, the radar device detects the pulse rate and the breathing frequency of buried people, separating these from arm and leg movements. And it does so with a high accuracy: It measures the pulse rate as accurately as 99%, as the comparison to portable pulse devices has shown.

The technology can also be used the other way around: By positioning the device at a stationary spot, vital signs of people moving in the area surrounding the device can be detected. This can make sense, for example, where there are numerous injured people needing first aid, for instance in a sports facility. The radar device can be used to capture the vital signs and match them to the respective injured persons. Who needs help most urgently? In this process, the algorithm primarily looks at changes: Is the heart fibrillating? Is the patient breathing very fast? Vital parameters are direction-dependent: When a person turns over, this has effects on his or her breathing. The changes in rhythm, while the breathing signal and the movement also overlap. The algorithm is able to break down these signals and show them separately.

The first algorithm is ready for use; the system has already been tested with a person walking past it at a distance of up to 15 meters. In the next steps, the system can be adjusted to different situations. Besides rescue services, one of these situations could be autonomous driving. Here, the ability to distinguish between living beings and other obstacles is fundamental for safety – a child running into the street calls for another evasive maneuver than a ball rolling into the street. The mobile radar is ideal for these questions as well.

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ANNEX

EDUCATION AND TRAINING

Lectures

WS 2018/2019

Bathelt, Andreas: »Digitale Regelungstechnik+ Advanced Control«, TH Köln

Bertuch, Thomas: »Antennen und Wellenausbreitung«, FH Aachen

Brüggenwirth, Stefan: »Kognitive Sensorik«, Ruhr-Uni-Bochum

Brüggenwirth, Stefan: »Cognitive Sensoric«, Uni Siegen

Caris, Michael: »Physikalisches Praktikum«, HS Bonn-Rhein-Sieg

Cerutti-Maori, Delphine: »Signal Processing for Radar and Imaging Radar«, RWTH Aachen

Heberling, Dirk: »High Frequency Technology - Passive RF Components«, RWTH Aachen

Heberling, Dirk: »Moderne Kommunikationstechnik - EMV für Mensch und Gerät«, RWTH Aachen

Knott, Peter: »Antenna Design for Radar Systems«, RWTH Aachen

Krebs, Christian: »Leiterplattendesign«, TH Koblenz

Pohl, Nils: »Integrierte Hochfrequenzschaltungen für die Mess- und Kommunikationstechnik«, Ruhr-Universität Bochum

Pohl, Nils: »Elektronik 1 - Bauelemente«, Ruhr-Universität Bochum

SS 2019

Bathelt, Andreas: »Digitale Regelungstechnik+ Advanced Control«, TH Köln

Caris, Michael: »Physikalisches Praktikum«, HS Bonn-Rhein-Sieg

Heberling, Dirk: »Elektromagnetische Felder in IK«, RWTH Aachen

Heberling, Dirk: »High Frequency Technology - Antennas and Wave Propagation«, RWTH Aachen

Knott, Peter: »Radar Systems Design and Applications«, RWTH Aachen

Krebs, Christian: »Leiterplattendesign«, TH Koblenz

Pohl, Nils: »Integrierte Digitalschaltungen«, Ruhr-Universität Bochum

Supervised doctoral studies

Cornelius, Rasmus: »Fast Sperical Near-Field Antenna Measurement Methods«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Funke, Dominic: »Ultra-Low-Power Schaltungen für Mikrosysteme in CMOS-Technologie«, Ruhr-Universität Bochum

Mauelshagen, Christine: »Energietechnische Innovationen in zentralen und dezentralen Versorgungssystemen«, Rheinische Friedrich-Wilhelms-Universität Bonn

Sandenbergh, Jacobus Stephanus: »Synchronising coherent networked radar using low-cost GPS-disciplined oscillators«, Universität Kapstadt/Südafrika

Welp, Benedikt: »Systemkonzept und Schaltungen für breitbandige MIMO-FMCW-Radarsysteme bis 60 GHz in modernen SiGe-Bipolartechnologien«, Ruhr-Universität Bochum

Wojaczek, Philipp: »Passive Radar on Moving Platforms Exploiting DVB-T Transmitters of Opportunity«, L'Università degli Studi di Roma "La Sapienza"

Supervised master theses

Baumhöfer, Jan: »Entwurf und Vergleich hocheffizienter Leistungsverstärker in SiGe-Technologien bei 80 GHz«, Ruhr-Universität Bochum

Berners, Johannes: »Development and Setup of an LTE Measurement Stand for Smartphones Based on a Software-defined Radio«, RWTH Aachen

Bündgen, Felix: »Entwicklung von 200 W TX- und RX-Baugruppen bei 2,4 - 5,0 GHz für die Bergnotrettung«, Fachhochschule Aachen

Cesbron Lavau, Louis: »DVB-S Passive Radar for Avalanche and Subsidence Detection«, RWTH Aachen

Deis, Hendrik: »Entwurf und Entwicklung eines Handheld Radar-Systems auf Basis eines 120 GHz FMCW-Frontends«, Ruhr-Universität Bochum

Ergin, Elcin: »Grating lobe suppression of phased array antennas using high impedance surface structures«, RWTH Aachen

Iqbal, Asif: »Design and implementation of a phase-noise optimized radar-frontend«, Universität Bremen

Laas, Stanislav: »Entwicklung eines 77 GHz Radar-Frontends mit MIMO-Signalprozessierung«, Ruhr-Universität Bochum

Mansour, Josef: »Design and Comparison of Resonance-based and Non-resonance Electromagnetic Liquid Sensors for Determination of Dielectric Properties in Chemical and Medical Applications«, RWTH Aachen

Müller, Peter: »Zentrale Speicherung gesammelter Daten von verteilten Radarsensoren«, FernUniversität Hagen

Nzalli Noubi, Sandra Corinne: »Detection of Objects using a C-Band FMCW Radar System for Surveillance of Hazardous Areas«, RWTH Aachen

Papurcu, Hakan: »Entwurf und Charakterisierung von SiGe-basierten Empfangsarchitekturen für ein 250 GHz FMCW-Radarsystem«, Ruhr-Universität Bochum

Phillip Müller: »Detektieren, Analysieren und Auswerten von eintreffenden Radarwellen durch Bestimmung ihrer Signalparameter«, Technische Hochschule Köln

Romstadt, Justin: »Design of Power-efficient-Integrated Transmitters for mm-wave radar applications above 120 GHz«, Ruhr-Universität Bochum

Sauter, Lina: »Development of a tool interoperability interface for the integration of a 3D rendering engine into a Co-Simulation environment for closed-loop testing of ADAS«, RWTH Aachen

Schiffarth, Anna-Malin: »Influence of the polarisation and measurement distance on the near-field-to-far-field transformation using compresse sensing methods«, RWTH Aachen

Schmitz, Lukas: »Vergleich und Entwurf von True-Time-Delay Konzepten für ein Ka-Band Phased-Array-Radarsystem in einer SiGe-BiCMOS-Technologie«, Hochschule Koblenz

Schwalm, Konstantin: »Investigation of the impact of subarray failures on the radiation pattern of 5G massive MIMO base station antennas«, RWTH Aachen

Springer, Jannik: »Radar waveforms and processing methods for frequency modulated wave operation to analyze orbital parameters of fragmenting objects in earth orbit«, RWTH Aachen

Striegel, Marcus: »Radargrammetric 3D Reconstruction of Detached Objects by Evaluation of the Shadow in Airborne Circular SAR Images«, RWTH Aachen

Valdes Crespi, Ferran: »Implementing a distributed clock for radar networks«, RWTH Aachen

Vizcarro i Carretero, Marc: »X-Band Patch Antenna Array with Low Cross-pol for Weather Radar Applications«, RWTH Aachen

PUBLICATIONS

To ensure that you have an up-to-date overview of our numerous publications in scientific journals and conferences, all of our publications are available with immediate effect on our website.

All publications 2019:
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Publications in scientific journals
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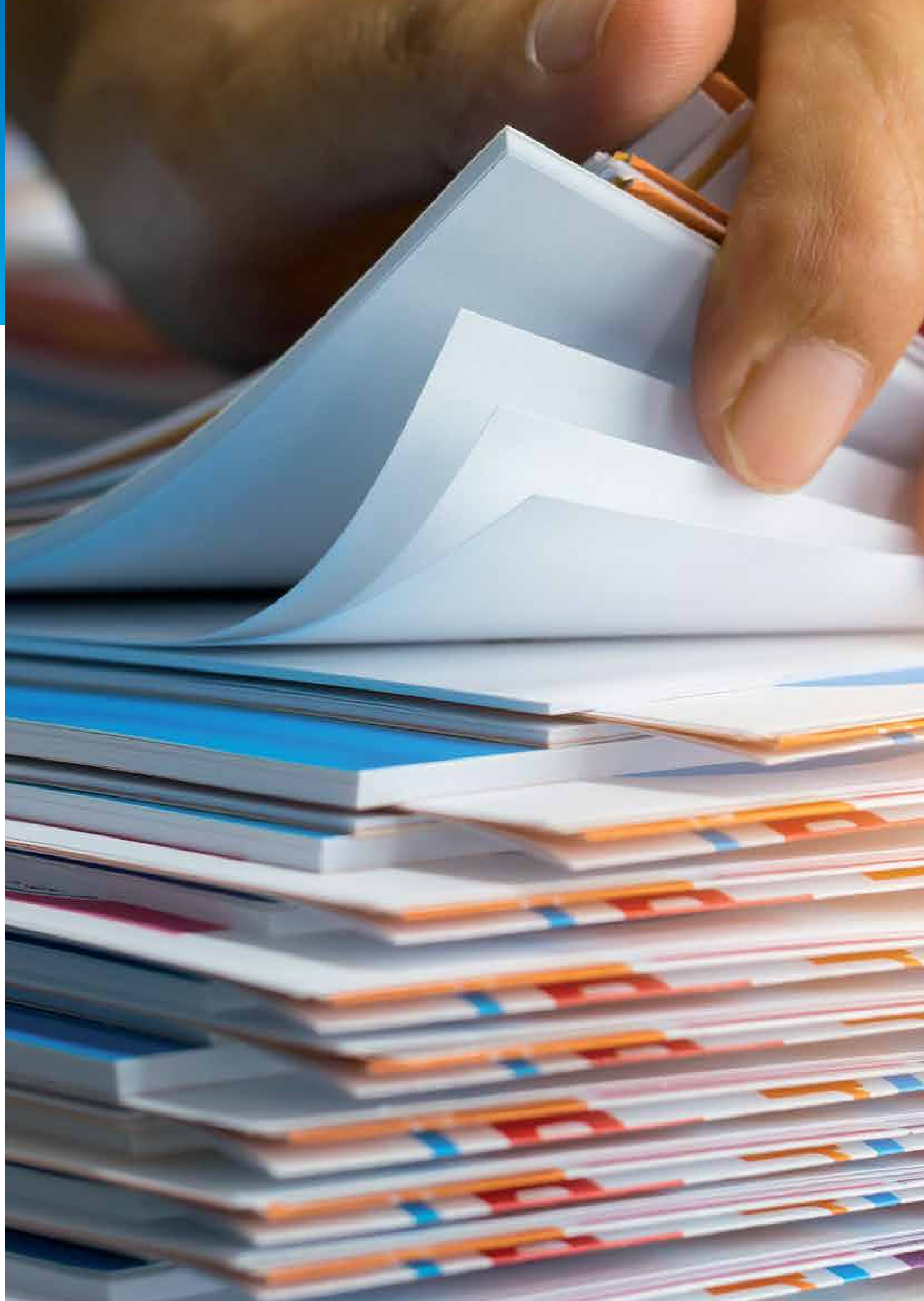


COMMITTEE ACTIVITIES

Behrendt, D.
- Deutsche Gesellschaft für Zerstörungsfreie Prüfung (DGZfP): Mitglied

Brüggenwirth, S.
- EEE AESS Germany Chapter: Secretary
- International Radar Symposium (IRS) 2019, Ulm: Technical Program Committee
- EDA Radar Captech: German Governmental Expert
- European Microwave Week (EuMW) 2019, Paris: Technical Review Committee

Cerutti-Maori, D.
- Inter-Agency Space Debris Coordination Committee (IADC): Nationale Vertreterin in der Working Group 1 (Measurements)
- IEEE Radar Conference 2019: Technical Review Committee
- Radar 2019: Technical Program Committee
- IEEE (Institute of Electrical Electronics Engineers): Senior Member

Cristallini, D.
- PCL on Mobile Platforms (SET 242): Co-Chair
- IEEE Radar Conference 2019: Technical Program Member
- European Microwave Week (EuMW) 2019, Paris: Technical Program Member
- International Radar Symposium (IRS) 2019, Ulm: Technical Program Member
- ICARES 2019, Technical Program Member
- SPSympo-2019, Technical Program Member
- AGERS 2019, Technical Program Member

Danklmayer, A.
- U.R.S.I. International Union of Radio Science, Commission-F Wave Propagation and Remote Sensing: Member
- VDE-ITG Fachausschuss 7.5 Wellenausbreitung: Mitglied
- Deutsche Gesellschaft für Ortung und Navigation (DGON): Mitglied im Fachausschuss Radartechnik
- International Radar Symposium (IRS) 2019, Ulm: Technical Program Committee

Heberling, D.
- European Conference on Antennas and Propagation (EuCAP) 2019, Krakau: Mitorganisator, Mitglied des Steering Committee
- Zentrum für Sensorsysteme (ZESS) 2019, Siegen: Wissenschaftlicher Beirat
- Antenna Measurement Technique Association (AMTA) 2019, San Diego: Past President
- Deutsche Forschungsgesellschaft (DFG): Fachkollegiat
- IMA (Institut für Mikrowellen- und Antennentechnik e. V.): Geschäftsführer
- IEEE (Institute of Electrical Electronics Engineers): Senior Member

Klare, J.
- International Radar Symposium (IRS) 2019, Ulm: Technical Program Committee, Award Chair
- European Microwave Week (EuMW) 2019, Paris: Technical Review Committee
- International Conference on Aerospace Electronics and Remote Sensing Technology (ICARES) 2019, Yogyakarta: Technical Program Committee
- International Conference on Digital Image and Signal Processing (DISP) 2019, Oxford: Technical Program Committee

Knott, P.
- Informationstechnische Gesellschaft (ITG) im VDE, Fachausschuss HF 4 „Ortung“: Vorsitzender
- IEEE Microwave Theory and Techniques (MTT) / Antennas and Propagation (AP) Joint Chapter, Executive Committee: Chair
- Deutsche Gesellschaft für Ortung und Navigation (DGON): Mitglied im Wissenschaftlichen Beirat, Vorsitzender Fachausschuss Radartechnik
- European Association on Antennas and Propagation (EurAAP): Gewählter Regional Delegate
- NATO Research and Technology Organisation (RTO): „Member at Large“ des Sensors and Electronics Technology Panels
- International Radar Symposium (IRS), Ulm: Chair

Leushacke, L.
- Inter-Agency Space Debris Coordination Committee (IADC): Nationaler Vertreter in der Working Group 1 (Measurements)

Matthes, D.
- Solutions Advancing next Generation Radar Electronic Attack (SCI 281): Chairman

Nüßler, D.
- Deutsche Gesellschaft für Zerstörungsfreie Prüfung (DGZfP): Mitglied
- VDI/VDE-GMA FA 8.17 Terahertz-Systeme: Mitglied
- European Machine Vision Association (EMVA): Mitglied
- International Radar Symposium (IRS) 2019, Ulm: Technical Program Committee

O'Hagan, D.
- Bi-/Multi-static radar performance evaluation under synchronized conditions, (SET-268): Chairman
- IEEE AES Magazine: Associate Editor for Radar
- IEEE Radar Conference 2019: Technical Program Member
- International Radar Symposium (IRS) 2019, Ulm: Technical Program Member

Pohl, N.
- IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes 2019, Bochum: TPC chair
- International Microwave Symposium (IMS 2019), Boston: Technical Program and Review Committee, Student Design Contest Organizer, Workshop organizer
- IEEE BiCMOS and Compound Semiconductor Integrated Circuits and Technology Symposium (BCICTS 2019), San Diego: Technical Program Committee, CO-Chair for MM-Wave & THz ICs
- International Radar Symposium (IRS) 2019, Ulm: Technical Program Committee
- IEEE Transactions on Microwave Theory and Techniques: Guest editor
- Springer Journal of Infrared, Millimeter, and Terahertz Waves: Associate editor
- VDI ITG Fachausschuss 7.3 Mikrowellentechnik: Mitglied
- IEEE MTT Technical Committee MTT-24 Microwave/mm-wave Radar, Sensing, and Array Systems: Member
- IMA (Institut für Mikrowellen- und Antennentechnik e. V.): Mitglied
- IEEE (Institute of Electrical Electronics Engineers): Senior Member

Rial Villar, F.
- EDA Remote Intelligence of Building Interiors (RIBI): German Governmental Expert

Walterscheid, I.
- IGARSS 2019: Scientific Committee
- IEEE (Institute of Electrical Electronics Engineers): Senior Member

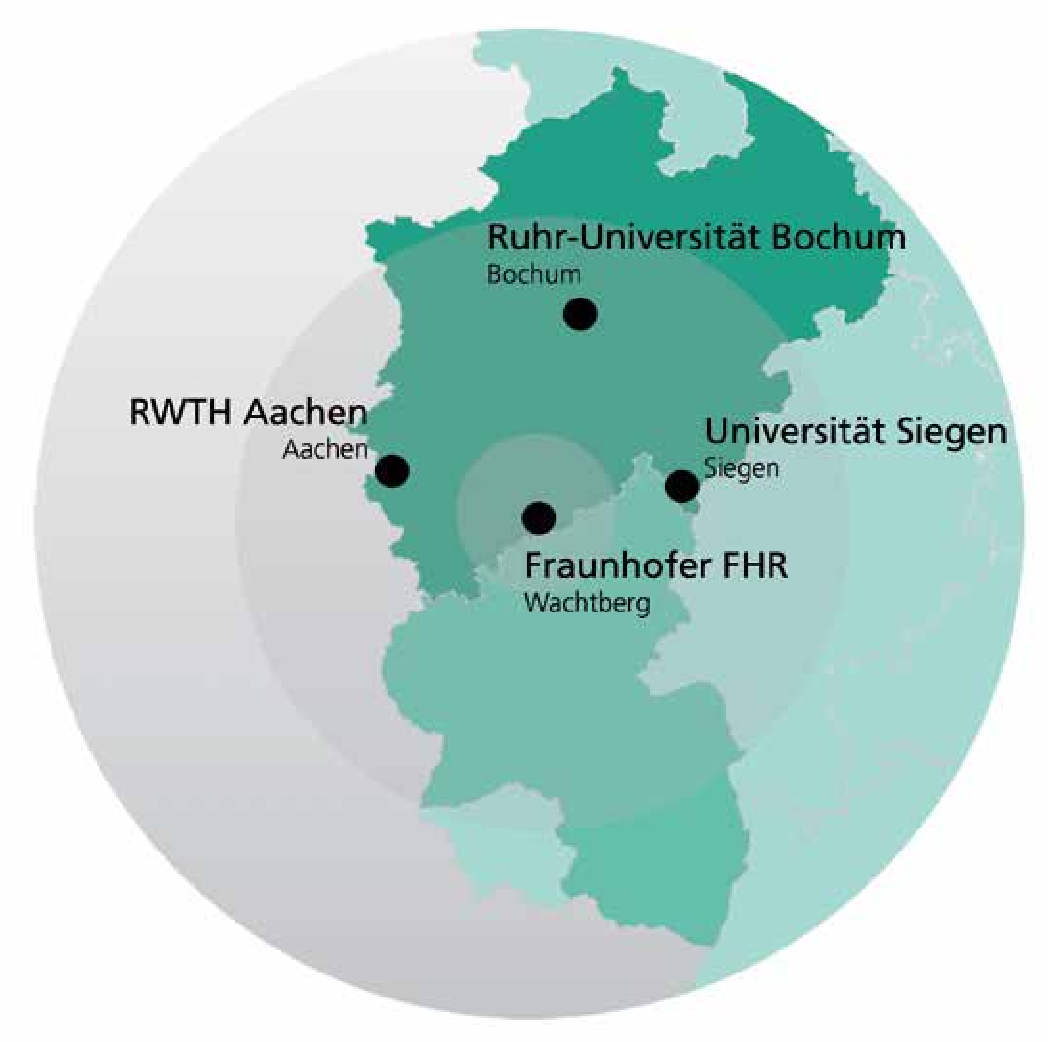
Weinmann, F.
- ITG-Fachausschuss 7.1 „Antennen“: Mitglied
- European Conference on Antennas and Propagation (EuCAP) 2019: Technical Review Committee
- EDA-Workshop on Radar Signatures and EM Benchmarks, 14. November 2019, Brüssel: Technical Program Committee
- EMWT 2019, Specialist Meeting on Electromagnetic Waves and Wind Turbines: Technical Committee Member

Weiß, M.
- International Radar Symposium (IRS) 2019, Ulm: Technical Program Member
- European Microwave Week (EuMW) 2019, Paris: Technical Program Member

Uschkerat, U.
- EDA CapTech Radar: German Governmental Expert
- BMVI Nationalen Vorbereitungsgruppe (NVG) & Arbeitskreis AK2 zur WRC-19: Mitglied
- ETSI TGUWB: Mitglied

LOCATIONS

The Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR has five locations in North-Rhine Westphalia.



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