Fraunhofer
FHR

Fraunhofer Institute for
High Frequency Physics and
Radar Techniques FHR

Annual Report 2021

For a secure future: Key technology radar

Anechoic chamber for spherical near-field scanning of complex antenna systems.

Annual Report 2021

For a secure future: Key technology radar

Preface

Dear friends and partners of Fraunhofer FHR, dear readers,

This annual report reaches you at a time when the world situation has changed in a way that was unimaginable only a short time ago. The large investments also in defense research announced by the Federal Government out of this situation show its importance for peace and security. Radar makes an important contribution here in many areas, as you can also read in this report.

In 2021, the impact of the Corona pandemic continued to influence our research work, whether through home offices, digital trade shows and conferences, presence rates in the laboratories, or the global shortage of commodities, which makes the implementation of various projects challenging. Nevertheless, we have moved our projects forward almost as before Corona. The topics are future-oriented: In the Fraunhofer-Gesellschaft's lead project Waste4Future, we are working in a consortium with seven Fraunhofer Institutes on innovative plastics recycling and contribute our expertise in sensor technology for waste sorting (report p. 59). Networked Fraunhofer expertise also characterized the RuLe project: Under the project management of Fraunhofer FHR, seven institutes conducted research into greater resilience of urban living spaces to harmful influences such as climate change, natural disasters and terrorist attacks (reports p. 28 and 29). The focus continued to be on the space situation: In view of the continuous increase in traffic in space, increasingly precise space monitoring is becoming indispensable. The GESTRA Tx2 project takes this into account with the development of an even more powerful transmitter unit for the GESTRA network (report p. 44 and 45).

Another milestone in the past year was the finalization of our institute strategy, with which we have optimally positioned ourselves for the future. You can find all about this on p. 8 and 9.

In July 2021, we were greatly moved by the flood disaster in the region, which also affected many Fraunhofer FHR employees, their families and friends. We offered support as quickly as possible, and the Fraunhofer-Gesellschaft also set up extensive aid programs. Many employees helped their colleagues on site. The team spirit in the Fraunhofer FHR community made a deep impression on us.

We have only become more aware of the great importance of personal exchange with you, our partners and customers, over the past two years. The few possible face-to-face events such as Space Tech Expo Europe 2021 in Bremen were highlights in our annual calendar. We are all the more pleased to invite you to our Wachtberg Forum 2022 on June 23. You can find all the information here: https://www.fhr.fraunhofer.de/wachtberg-forum.

We hope you enjoy reading this issue!

Best regards

Peter Knott　　Dirk Heberling

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Table of Content

Fine-tuned for you: Our institute strategy 2021-2026

We are Europe´s leading radar research institute and are setting technological trends with which we have made a sustainable contribution to greater security, safety and efficiency in society and business in recent years and will continue to do so in the future.

We are proud of this – verifiable – position and we not only want to maintain it, but to further expand it for the benefit of our customers and partners from industry, research and public institutions. We have achieved it by consistently expanding and deepening our core competencies since the founding of the institute and by continuously adjusting our course to market needs. This enables us to support your business areas in the best possible way with our cutting-edge technologies. As a Fraunhofer Institute, every five years we take advantage of the valuable view of top-class external experts on our institute and evaluate our strategic orientation with them in an audit. This was the case again in November 2021. We were able to fully convince the invited experts from industry and research with our Strategic Plan 2026+. Thus, we are convinced to continue to provide you with unique added value and competitive advantage for your working environment and product portfolio with our work around radar and high-frequency sensor technology. This is our mission.

Our business areas have seen almost consistent positive growth over the last few years, confirming that our work has its finger on the pulse of the times and your needs. For the next five years, we are therefore aiming for an overall budgetary growth of around ten percent per year, combined with a corresponding increase in personnel. By increasing our share of economic revenue to over 30 percent in the long term, we want to apply our research even more consistently in line with Fraunhofer's mission.

We have based our Guiding Strategy 2026 on seven pillars that will ensure the success we and you are striving for:

Defense and space observation: Our research for greater security in Germany and Europe

Of course, our core businesses of defense and space continue to play a major role. Our unique comprehensive expertise built up over decades to detect, track and analyse near and far-off objects makes our sensor technology and algorithms indispens-able components for defense and security tasks on Earth and for our satellite-based infrastructure in space. For an overview of our offerings and examples of ongoing work in these areas, see the chapters on p. 30 and 31 and p. 42 and 43. For example, we are modernizing our proven TIRA Tracking and Imaging Radar by 2025 and making it even more powerful with new capabilities. In combination with our successfully launched new development GESTRA and its planned followon projects, some of which have already been started – read more about them on pages 44 and 45 – we offer you unique capabilities for space situational awareness.

Not only since the upsetting events in Ukraine, Germany and its European partners have been working to modernize their defense systems to maintain German and European sovereignty. Four major military projects – FCAS, MGCS, AFSC and ECRS – have already been launched or are currently in the process of being decided. We have focused our defense research on supporting these four major projects. Radar and high frequency technology is essential for the surveillance and reconnaissance performance of these systems, and so we can and want to make a decisive contribution to security in Germany and Europe with our in-depth know-how!

Effectiveness, sustainability and safety and security also for transport, medicine and production

We have also aligned our civil research and development priorities to the most promising and pressing trends of the moment. This includes sensor technology for new, increasingly autonomous mobility, as in the KonSens project for automated evaluation of intersections (see p. 55), as well as for the future market of civil drone systems in our Business Unit Traffic. We are developing solutions for greater resilience for our cities (project example RuLE, p. 50 and 51) in our Business Unit Security as well as for greater sustainability in production, for example through technologies for non-destructive testing (see p. 58) or effective materials cycles (project example: Waste4Future, p. 59) in our Business Unit Production.

We are also working to tap radar applicationscloser to people, for example for medical purposes, by miniaturization radar systems while maintaining or increasing their performance and simplifying their handling in our Human and Environment business Unit (project example M3Infekt, p. 62 and 63).

Through targeted cooperation, especially within the Fraunhofer world, we can offer you the entire portfolio from customized individual components to perfectly integrated overall sensor systems and from studies to prototype construction and small series.

Of course, we have also closely examined our internal processes for this purpose in this strategy process. For example, with thematically clustered think tanks and new internal cooperation opportunities, including the introduction of SAP, we want to make our bundled know-how available to you even more efficiently for your projects in the future.

Let´s design the future together and develop solutions for your business areas. We are ready!

Our vision mission statement

With our radar and highfrequency sensor technology, we make the products and work of our customers and partners, and thus society in the 21st century, safer, more efficient and more comfortable.

To achieve this, we do research and develop tailored high-frequency and radar systems every day as essential components for mobile and stationary environment sensing for our customers and partners in the business units Defense, Space, Security, Production, Traffic, and Human and Environment.

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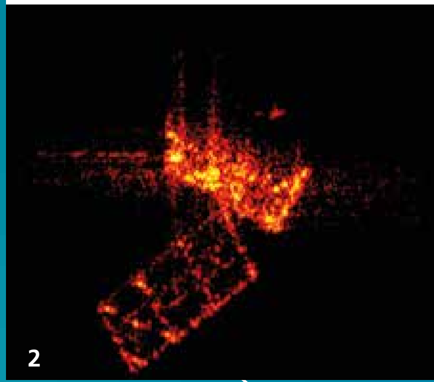
Special events in 2021

Online, April 1
EuSAR Best Paper Award
Great success: A team of Fraunhofer FHR receives the EuSAR Best Paper Award for their paper »ISAR imaging by integrated Compressed Sensing, range alignment and autofocus« .


2

Düsseldorf/Online, March 22 - 26
EuCAP – The 15th European Conference on Antennas und Propagation
15 technical sessions, 4 poster sessions, 1 invited speaker session from Fraunhofer FHR.

Leipzig/Online, March 29 - April 1
EUSAR 2021 - 13th European Conference on Synthetic Aperture Radar
2 tutorials, 5 lectutres, 8 chairs from Fraunhofer FHR

January

February

March

Utrecht/Online, January 10 - 15
EUROPEAN MIRCROWAVE WEEK 2020
Fraunhofer FHR participated with 15 lectures, Prof. Peter Knott held the key note. The projects ATRIUM, SAMMI and GESTRA were presented at the virtual booth.

1

Online, February 19
SET Panel Excellence Award for Dr. Matthias Weiß
With this award, NATO recognizes the outstanding contribution of Dr. Weiß in the SET Task Group »Design and Analysis of Compressive Sensing Techniques for Radar and ESM Applications«.

Darmstadt/Online, April 20 - 23
8th European Conference on Space Debris by ESA/ESOC
2 lectures, 3 poster sessions, 2 chairs of Fraunhofer FHR

Online, June 21 - 22
21st International Radar Symposium (IRS 2021)
Fraunhofer FHR actively supported DGON in realizing the digital event. Radar experts from science and industry as well as researchers and students took the opportunity to participate online. The more than 140 international participants shared and discussed current research results and developments. Fraunhofer FHR participated with two focus sessions on Automotive Radar for Automated Driving: Landmark-based RADAR SLAM for Autonomous Driving and Weather Radar: A new airborne network concept to improve air navigation safety as well as the panel discussion on AI and Radar.

Online, June 21
Prof. Joachim Ender receives Christian Hülsmeyer Award
The German Society for Positioning and Navigation (DGON) presents the award at IRS for Prof. Ender's outstanding contributions to radar research and education.


6

Wachtberg, June 1
Dr. Stefan Brüggenwirth appointed NATO SET Panel Member at Large for Artificial Intelligence and Machine Learning.


3

Online, April 23
NATO SET Panel Early Career Award for Dr. Christoph Wasserzier

April

May

June

Villip/Online, May 26 - 27
Passive Radar & Multistatics Focus Days 2021


4

Munich/Online, June 22
Fraunhofer Solutions Days
At the Safe Society and Industry theme day, project manager Dr. Dirk Nüßler presented the interdisciplinary RuLe project for analyzing and improving the resilience of urban living spaces, in which seven Fraunhofer institutes are pooling their expertise.


5

Online, June 12
Manjunath Thindlu Rudrappa receives ARGUS Award at Hensoldt Professor Day

7

July

Wachtberg/Online, July 2
Digital Board of Trustees Meeting – streamed live
From all over Germany, the members of the board of trustees joined in and discussed the institute's current topics and developments with the directors. This year, for the second time in a row, a broadcast was offered to the employees; more than 70 interested people took the opportunity to follow the event live on their computers.

July 5 - 8
International Summer School on Radar/SAR 2021
Digital premiere: students, PhD students and young scientists from all over the world took the opportunity for further education, exchange and networking. 75 participants from 17 countries met online and completed the program of lectures, workshops and social events, which was excellently staffed with international radar experts.

Ahrtal, July 14
Flood catastrophe in the region
Out of nowhere, the devastating flood disaster hits the region. Also many employees of Fraunhofer FHR, their families and friends are affected.

August

Wachtberg, August 15
60th birthday
Prof. Dr.-Ing. Dirk Heberling


8

September

September 2
VDI sponsorship award of the VDI Rheingau-Bezirksverein e.V. for Lukas Liebelt


9

Aachen, September 15
Bonding Automotive Day

Linstow, September 27 - 29
23rd DWT Naval Workshop »The Navy and its Future Development as a Contribution to the Capability Profile of the Bundeswehr«.
A rare presence event: Fraunhofer FHR showed, among other things, the possibilities of cognitive systems in airspace surveillance. In a live simulation at the booth, the application possibilities of the cognitive radar simulator CoRaSi in the field of air defense were demonstrated. Likewise, colleagues showcased capabilities in measurement and simulation technology through examples of the application of metamaterials technology for military antenna applications.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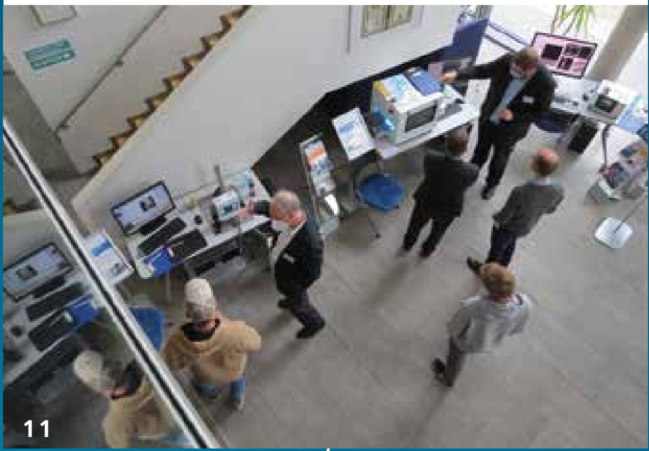
Fürth, October 27 - 28
Fraunhofer Vision Technology Day



11

Wachtberg/Online, November 16
RuLe Workshop

Hamburg, November 11
Innoday FüAK BW

Stuttgart, November 8 - 10
MST Kongress

Online, November 23 - 24
ISTAR-Workshop

Online, November 9
Jobarea20

October

November

December

Aachen, November 2.
Bonding

Bremen, November 16 - 18
Space Tech Expo Europe 2021
At the joint booth of the Fraunhofer Space Alliance, the institute presented the capabilities of TIRA and GESTRA. With well-visited halls, the colleagues had many interesting conversations and contacts at the booth.

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Wachtberg/Online, November 4
Strategy Audit 2021

Radar in Action: The Success Story Continues

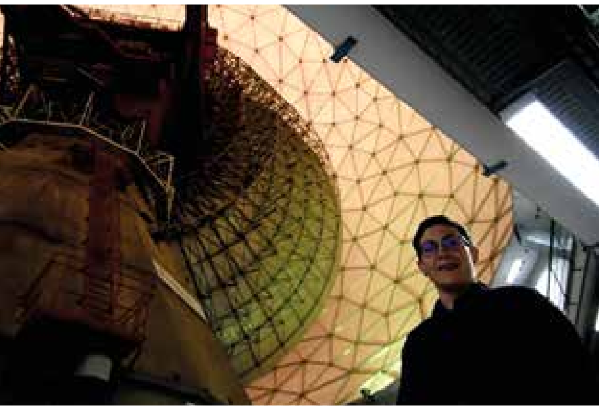
In 2021, the restrictions of the Corona pandemic continued to have an impact on interaction and networking with customers and partners. Trade shows, conferences, our annual Wachtberg-Forum – Corona meant that many opportunities for personal contact continued to be put on hold. Shortly after the pandemic began, Fraunhofer FHR, with the active support of many researchers, developed the online lecture series »Radar in Action«: an innovative, digital format to vividly present our research work to our target groups. The first broadcast started on June 23, 2020. The series was a complete success: over 900 people attended on 20 dates in 2020. So it was clear: We will continue! And so, in 2021 also, the motto was always on Tuesdays at 2 p.m.: From Wachtberg to the world!

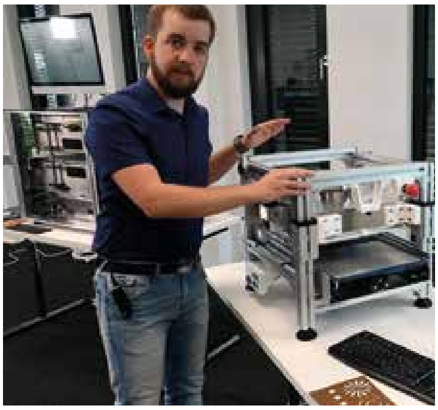
A wide range of topics

On 19 dates in 2021, our researchers presented the latest results of radar research to experts and interested laypersons from industry, politics, science and society. Practice-oriented and compact, current projects were presented from the broadcast studio at the Villip site for 30 minutes each, often with live presentations of the experimental systems, always with an opportunity for questions and discussion. The top 3 presentations last year reflect the wide range of topics: In 1st place with 198 participants was »Machine Learning for Radar applications – Classification of Targets using Neural Networks« by Simon Wagner. Second place went to »High-resolution imaging with a 240-Ghz radar with SiGe chip« by Prof. Dr.-Ing. Nils Pohl and Dr.-Ing. Reinhold Herschel with 153 spectators. Close behind in third place was the presentation »Danger from drones: Monitoring airports with millimeter wave radar« by Winfried Johannes with 148 participants.

Internationality is emphasized

Radar in Action is held in German or English. The many English-language events attract participants from all over the world. From Belgium to Thailand: in 2021 there were spectators from 60 countries.





Missed a lecture? No problem! Now also on Youtube!

The live character with the possibility to ask questions directly make Radar in Action stand out. Nevertheless, many participants would like to watch the lecture again or could not keep an appointment. Since 2021, a large part of the lectures is therefore posted on Youtube - always 14 days after the event.

The presentations can be found at: https://www.fhr.fraunhofer.de/de/veranstaltungen/online-vortragsreihe--radar-in-aktion.html

Top marks from content participants

The feedback we regularly receive from participants speaks for itself: In 2021, 93% rated the presentations as very good or good overall. This great result makes us very happy and motivates us even more to continue presenting exciting projects in the future. Be there: All information on Radar in Action with topics, dates and registration options can be found at www.fhr.fraunhofer.de/RadarinAktion. Participation is free of charge.

RADAR IN AKTION

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Doctorate at Fraunhofer FHR

Dr.-Ing. Sven Thomas

In July, Dr. Sven Thomas, a member of the Bochum Research Group and the Chip Design Group of the Integrated Circuits and Sensor Systems Department, defended his doctoral thesis »System and antenna concepts for an FMCW radar system based on a 240 GHz SiGe transceiver MMIC«.

After completing his master's degree in electrical engineering and information technology at Ruhr-Universität Bochum (RUB), Prof. Dr.-Ing. Nils Pohl brought him to Fraunhofer FHR in 2013, where Dr. Thomas worked on chip and system development with higher frequencies (keyword 240-GHz radar) in the newly founded Chip Design group. This resulted in his dissertation, supervised by Prof. Pohl, which deals with the development of a compact and precise FMCW radar sensor that achieves a modulation bandwidth of 52 GHz in the frequency range around 240 GHz. The basis of this system is a SiGe transceiver MMIC developed in cooperation between RUB and Fraunhofer FHR, fabricated in Infineon's B11HFC SiGe BiCMOS technology.

By integrating any high-frequency components on the MMIC, including on-chip antennas, costly high-frequency PCBs can be eliminated. The result: a compact, cost-effective and robust design that can be used in confined spaces and harsh industrial environments. The wide FMCW modulation bandwidth enables high range resolution, ensuring high selectivity and image resolution even in complex measurement scenarios. »The core of my work relates to an unwanted effect of the sensor: The radar emits a 120 GHz signal at half the frequency in addition to the desired frequency at 240 GHz. This leads to false targets at half the range. To prevent this, I designed a frequency-filtering plate based on an interference filter that suppresses this half frequency. Then, this filter structure was integrated into the existing drop-shaped lens. Thus, I developed a frequency-filtering dielectric lens, for which a patent application has been filed,« explains Sven Thomas.

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The promotion of scientific excellence is an important concern of Fraunhofer FHR. The institute therefore actively supports scientists on their way to doctoral studies. Depending on the personal research focus and interests, there are individually tailored supervision and support options.

Dr. Iole Pisciottano

In early 2021, Dr. Iole Pisciottano successfully defended her PhD thesis entitled »Multidimensional Passive ISAR for Maritime Target Imaging«. The 37-year-old works in the Passive Radar and Anti-Jamming Techniques department, in the Passive Sensor Network group of Dr. Diego Cristallini, who was also the supervisor of her thesis. She received her PhD at the Sapienza University in Rome under Prof. Debora Pastina (Department of Information Technology, Electronics and Telecommunications).

The PhD deals with novel ISAR (Inverse Synthetic Aperture Radar) approaches for passive maritime target imaging. Among the available illuminators of opportunity, her work focuses on digital video broadcasting signals such as DVB-T and DVB-S. The combined exploitation of DVB-T and DVB-S is extremely attractive for passive imaging purposes because they have complementary characteristics in terms of operating bandwidths, transmitter locations, and signals polarizations. Dr. Pisciottano developed ad hoc processing techniques to maximize the extracted information from the acquired ISAR products. In particular, she considered coherent and non-coherent multidimensional methods in terms of frequency, angle, and polarization, and validated them with experimental data from field trials.

Dr. Pisciottano worked at the Institute for three years as principal investigator of the BMBF project »Radar Signal Processing for Determination of Biomass of Barley Ears in Stands« after graduating in Telecommunications Engineering from the University Federico II in Naples. After a break and the birth of her child, she came back in 2017. A PhD was the goal from the beginning. Due to the department's good contacts to and thematic overlaps with Sapienza University, the choice fell on Rome. »The supervision from Fraunhofer FHR and the university went very well and I really appreciated the opportunity to work regularly on site in Rome. Unfortunately, the conclusion with the defense could only take place online due to corona – but that also worked out well,« says Dr. Pisciottano.

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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 BMVg (the German Federal Ministry of Defense) 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 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 and the basic financing by the federal government and the federal states.

In 2021, in its defense and civil segments, Fraunhofer FHR generated total income of €42.2 million.

Fraunhofer FHR had a total headcount of 390 at the end of 2021. Of these, 217 are permanent employees and 126 are temporary. The 47 remaining employees are students and apprentices.

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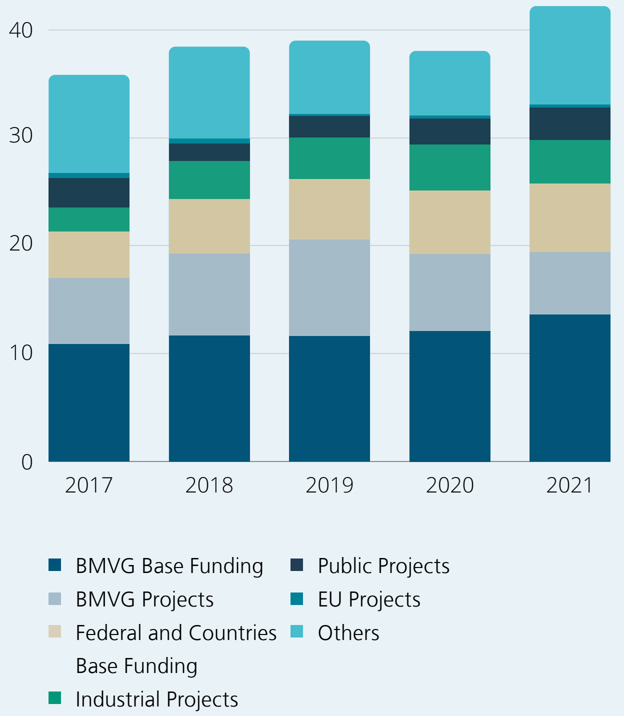
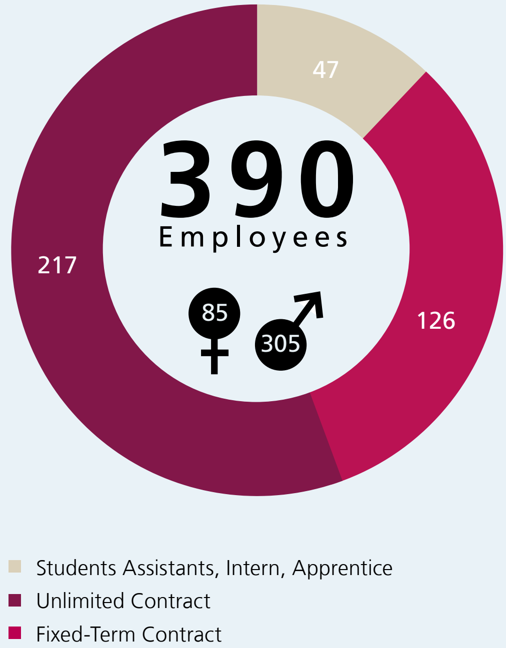
The year 2021 in numbers

Budget Development



Staff



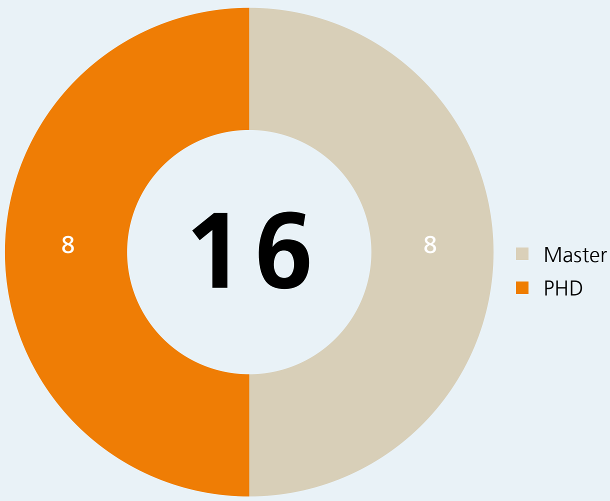
Professorship

Lectures

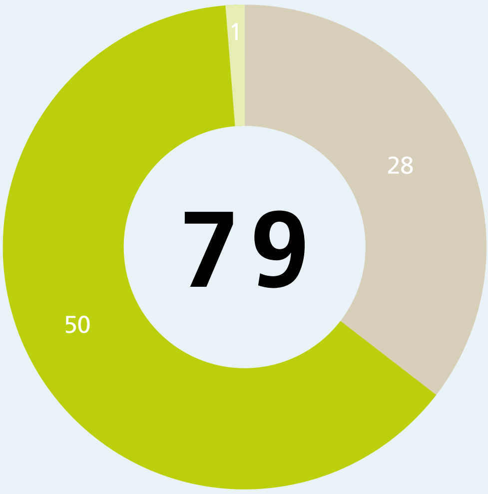
Wintersemester 20/21: **12**

Summersemester 21: **5**

Degree Thesis



Publications



- Journals
- Conference Paper
- Reviews

»Radar in Action« Online Lecture Series

19 Online lectures

97 Participants per lecture on average

Evaluation of participants: **93%** very good or good

Participants nations: **60**

Recordings on Youtube: **60**

Twitter: dt. 1697, engl. 1601

Facebook: 1127

Instagram: 1229

LinkedIn: 2056

YouTube: 497

Media Analysis

Articles in the media: **99**

Reached contacts: **36 Mio**

Organization Chart

Business Units

- **Defense** – Dr.-Ing. UDO USCHKERAT
- **Space** – DANIEL BEHRENDT, MBA (komm.)
- **Security** – DANIEL BEHRENDT, MBA (komm.)
- **Traffic** – Dr.-Ing. ANDREAS DANKLMAYER
- **Production** – DANIEL BEHRENDT, MBA
- **Human and Environment** – DANIEL BEHRENDT, MBA (komm.)

FRAUNHOFER INSTITUTE FOR HIGH FREQUE

Directors

Prof. Dr.-Ing. PETER KNOTT

Prof. Dr.-Ing. DIRK HEBERLING

Head of Administration

Lic. oec. HSG ULF HERZER

Head of Department
Antenna Technology and Electromagnetic Modelling (AEM)

Dr.-Ing. FRANK WEINMANN

- Electromagnetic Modelling
- Antennas and Front-End Technology
- Engineering and Security
- Antenna Technology for Multifunctional Apertures

Head of Department
Array based Radar Imaging (ARB)

Dr.-Ing. ANDREAS BRENNER

- Array based High Power Transmitting Technology
- cmW Array Systems
- Cryogenic Arrays
- Mechatronical System Design
- mmW Array Systems
- Operations
- Radar Imaging Methods
- Radar Intelligence
- Sensor centric Digital Appliances
- Signal Processing for Surveillance Radar
- Software Engineering

Head of Department
High Frequency Radar and Application (HRA)

Dr. rer. nat. STEPHAN STANKO

- Sub-mmW Radar Frontends
- Digital Backend Design & System Programming
- Planar Construction & Integration Technology
- Experimental Measurement Methods
- SAR & Algorithms @mmW

Head of Department
Integrated Circuits and Sensor Systems (ISS)

Dr.-Ing. DIRK NÜßLER

- Industrialized High Frequency Technology
- Embedded Systems and Algorithms
- 3D Sensor Systems
- Chip Design

NCY PHYSICS AND RADAR TECHNIQUES FHR

Institutes Locations

Headquaters: Wachtberg

Secondary locations: Aachen, Bochum, Siegen

RWTH Aachen

Institute of High Frequency Technology
Director: Prof. Dr.-Ing. DIRK HEBERLING

Research Group Aachen
Dr.-Ing. THOMAS DALLMANN

Research Group Bochum
Prof. Dr.-Ing. NILS POHL

Research Group Siegen
Prof. Dr.-Ing. JOACHIM ENDER

Staff Units

Head of Department Cognitive Radar (KR)
Dr.-Ing. STEFAN BRÜGGENWIRTH

- Non Co-operative Identification
- UWB Radar
- Adaptive Sensing and Perception
- Radar Architectures
- Machine Learning for Radar Applications

Head of Department Passive Radar and Anti-Jamming Techniques (PSR)
Prof. Dr. DANIEL O'HAGAN

- Passive Sensors and Countermeasures
- Passive Covert Radar
- Experimental Systems
- Passive Coherent Location

Head of Department Radar for Space Observation (RWB)
Dr. rer. nat. LARS FUHRMANN (komm.)

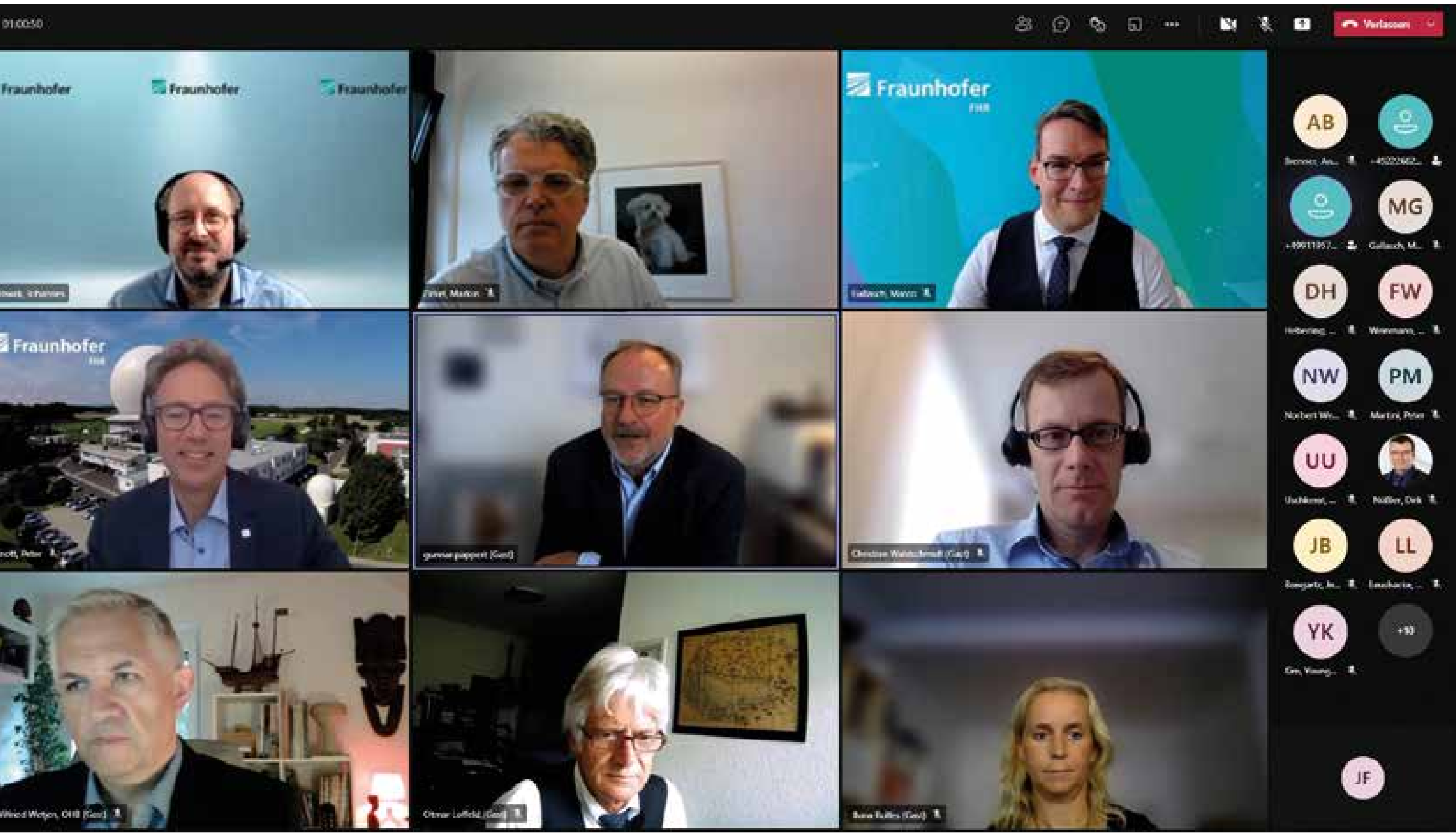
- Space Situational Awareness
- Techniques for Space Observation
- Space Reconnaissance
- TIRA High Frequency Systems & Radar Operations
- TIRA Signal Processing & Digital Systems Engineering
- TIRA Antenna System and Infrastructure

Administration
Lic. oec. HSG ULF HERZER

- Finance & Controlling
- Procurement & Equipment Management
- Human Resources
- Facility Management & Building Technology
- Information Technology

The Board of Trustees

The Board of Trustees supports our research work and advises the Institute Director and the Executive Board of the Fraunhofer-Gesellschaft. The members of our Board of Trustees from industry, science and ministries are:



Due to Corona restrictions, the Board of Trustees meeting on July 2, 2021 was held virtually, as in the previous year. The report of the Board was given by Dr. Markus Zirkel, Head of the Legal Department of the Fraunhofer-Gesellschaft.
In the image (from top left): Dr. Johannes Nowak (Research Coordinator, Fraunhofer-Zentrale), Dr. Markus Zirkel (Director Legal Department, Fraunhofer-Zentrale), Marco Gallasch (Head Strategy and Organizational Development, Fraunhofer FHR), Prof. Dr. Peter Knott (Director, Fraunhofer FHR), Gunnar Pappert, Prof. Dr. Christopher Waldschmidt, Winfried Wetjen, Prof. Dr. Otmar Loffeld und Prof. Dr. Ilona Rolfes.

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Research Fab Microelectronics Germany (FMD)

The central partner for business and science, politics and society

Since 2017, Fraunhofer FHR, together with another ten institutes of the Fraunhofer Group for Microelectronics and the two institutes FBH and IHP of the Leibniz Association, has formed the cross-location Research Fab Microelectronics Germany, or FMD for short. For the first time, 13 institutes from the two research organizations Fraunhofer and Leibniz are pooling their expertise here under one virtual roof, thus bringing a new quality to the research and development of micro- and nanosystems. With more than 2,000 scientists, the FMD is the largest R&D association of its kind in the world. With its unique diversity of competencies and infrastructures at the institutes, it is helping Germany and Europe to further expand their leading position in research and development.

Transition to regular operation

Until the end of 2020, the FMD was in the start-up phase. The extensive investment by the German Federal Ministry of Education and Research (BMBF) in modernizing the institutes was completed by the end of 2020 / beginning of 2021, with the exception of a few delays caused by the Covid19 pandemic.

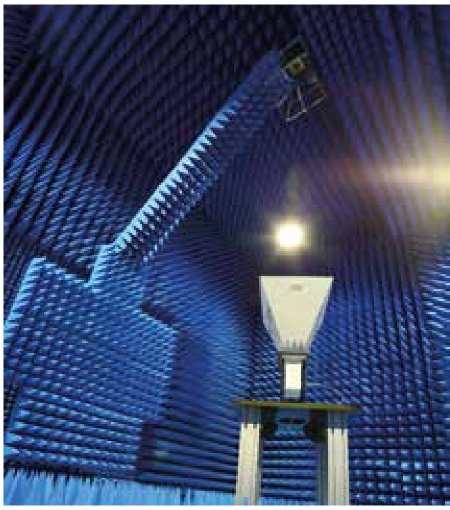
At the beginning of 2021, FMD started steady operations with the merger of the two offices of the Fraunhofer Group for Microelectronics and the Research Factory Microelectronics Germany and the new head of the joint office, Dr. Stephan Guttowski. This transition was marked by the digital conference »Impulsgeber FMD: Angebot & Potenzial – Köpfe & Know-how« on April 22, 2021. The model of interdisciplinary and interorganizational cooperation in the German research landscape is already bearing its first fruits and is also intended to serve as a model at the European level in the future.

With networking and cooperation to technological sovereignty

In the meantime, the FMD is considered a role model when it comes to positioning the competencies of different R&D institutions with a common strategy and a bundled offering to industry. With its cross-location, cross-technology and cross-competence cooperation, FMD ensures that technological sovereignty is maintained and expanded along the entire value chain. The office in Berlin represents the FMD institutes and acts as a central point of contact for all issues relating to micro- and nanoelectronic research and development in Germany and Europe.

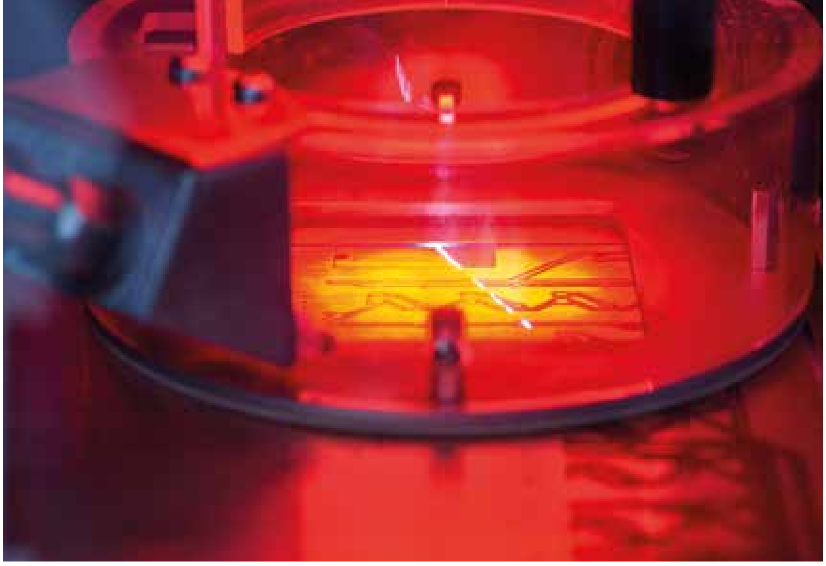
Versatile cooperation opportunities

In addition to the range of services for its customers from industry, FMD also offers a wide variety of cooperation opportunities for its partners in science and education. These are aimed directly at cooperative processing of research questions, such as joint work in joint projects and the operation of joint laboratories, the so-called Joint Labs. A major opportunity for cooperation in this context is the testing of special concepts and solutions from basic research on the facilities of FMD's institutes in order to gain a better understanding of their suitability in more application-oriented environments.



top:
Anechoic chamber for spherical near-field scanning of complex antenna systems.

below:
Printer – based on selective laser sintering for polymers with a build volume of 340mm x 340mm x 600mm.



The laser milling machine is part of the rapid prototyping chain and mills highly integrated structures into a PCB, which is needed for the development of mmW systems on short notice and in a timely manner.

Antenna anechoic chamber for complex radar systems

One of the key competencies that Fraunhofer FHR brings to FMD is antenna measurement technology. What are the properties of antennas for radar systems – for example, what are their directional characteristics? An antenna anechoic chamber, which was acquired within the scope of the FMD, will in future enable precise examinantions of individual and array antennas in the frequency range from 300 MHz to 50 GHz. The chamber itself has been completed and is already in test operation. Currently, work is still being done on the »range assessment« – i.e. on checking the test field. This involves the anechoic chamber being characterized according to specified criteria in order to be able to prove the quality of the measurements. Even the smallest antennas can now be analyzed at Fraunhofer FHR with FMD infrastructure: For example, on-chip antennas, i.e. antennas that are one to two millimeters in size and integrated on a chip.

Additive manufacturing of high-frequency boards

Another new acquisition addresses the additive manufacturing of high-frequency structures: These are metal printers and plastic printers on an industrial scale. While 3D printers familiar from home can only produce small structures and small quantities, these printers allow the production of volumes of up to one cubic meter. Another special feature: the metal printer is also capable of printing waveguide structures. The plastic printer also opens up numerous new possibilities: For example, printing antenna structures, lenses and housings.

Producing & testing prototype boards at short notice

FMD's investment funds were used to purchase laser milling machines, placers and bonders, among other things, which enable prototypes to be produced quickly. This allows both subsystems and complete radar systems to be built. To test the subsystems, the boards are measured directly within the circuits in the high-frequency range up to 500 GHz using an on-wafer measuring station. Using the FMD equipment at Fraunhofer FHR, these subsystems can be measured in advanced development stages for their intended use up to one terahertz. Among other things, a low-echo anechoic chamber is used for this purpose, which can be used for tests from eight gigahertz. For example, the functionality of built-up radar front ends can be checked using test objects.

With the help of different software, the measuring devices can be specifically controlled with the desired parameters and evaluated on the receiving side. This allows Fraunhofer FHR to simulate various application scenarios for the subsystems and test them directly for specific properties such as signal linearity.

E-plane sector horn with stepped matching to free space wave impedance for V and D band.

Forschungsfabrik Mikroelektronik Deutschland

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Future topics: Good starting position from the Corona crisis

The Corona pandemic is leaving its mark on industry and thus also on the Fraunhofer-Gesellschaft. In order to mitigate the effects of Lockdown and Co., the Fraunhofer-Gesellschaft pursued a strategy of competence and capacity preservation coordinated with the BMBF, within the framework of which programs were set up to promote future topics.

The corona pandemic poses major challenges not only for society but also for industry. The forecasts for 2021 show an encouraging picture across all Fraunhofer institutes. Nevertheless, quite a few institutes anticipate significant declines in economic output. The German Federal Ministry of Education and Research (BMBF) responded with a comprehensive economic stimulus package, which included a funding line entitled »Support for application-oriented research for non-university research institutions. The grants applied for by Fraunhofer were invested with a view to the future: Through the Innopush program, Fraunhofer provided targeted funding for future-oriented topics in order to support a powerful start to the industry's emergence from the crisis. 30 projects received one-year funding with a total volume of around € 73 million, the starting signal was given on February 1, 2021 – including for three projects in which Fraunhofer FHR is participating.

Terahertz Sprint: Terahertz Technologies for Communication and Sensor Technology

A special example of success was the project »Terahertz Sprint – Terahertz Technologies for Communication and Sensor Technology«, which was led by Fraunhofer FHR and also involved the Fraunhofer Institutes ENAS, HHI, IAF, IMS, IAF, IPMS, ITWM and IZM. Like all Innopush projects, the project was actually designed to run for one year. However, the concept was so successful that the BMBF decided to provide a larger grant instead after only three months: the joint project T-KOS, short for »Terahertz Technologies for Communication and Sensor Technology«, with a funding volume of almost ten million euros. T-KOS will run until the end of March 2022, with support from the office of the Forschungsfabrik Mikroelektronik Deutschland (FMD); in addition to the Fraunhofer institutes mentioned above, the Leibnitz institutes FBH and IHP are also participating in the project. In other words, the project's goal of acquiring follow-up projects was achieved at record speed.

But back to the Innopush project Terahertz Sprint, here the consortium pursued three major topics: terahertz communication, optical terahertz imaging, and the construction of an industrial-grade, multistatic terahertz imaging system. Fraunhofer FHR contributed its expertise primarily in the area of the imaging system: With the development of a

left:
The HALQ project was all about semiconductor-based quantum computing.

Heavy rain events can threaten the infrastructure of cities.

line scan camera that can be used to monitor production processes at 300 gigahertz non-destructively and in real time – including corresponding signal processing based on artificial intelligence. Despite the short project duration, partial results were successfully achieved and are being incorporated into the T-KOS joint project.

RuLe: Resilience of urban living spaces

The RuLe project aimed to increase the resilience of urban living spaces to harmful influences such as climate change, natural disasters and terrorist attacks through technologies, concepts and structures. Originally, the project was to be funded through the internal »Lead Projects« program, but this was halted in the wake of the pandemic. Fortunately, the consortium was finally able to acquire funding through the Innopush program. Here, too, Fraunhofer FHR was in charge, and the Fraunhofer Institutes IMS, LBF, IML, FKIE, INT and IAO also contributed their expertise. The main focus was on the catastrophes of tunnel fires and heavy rainfall. Questions about how supply paths can be maintained after a tunnel fire were the focus of the project. (see chapter on security)

HALQ: Semiconductor-based quantum computing

In the third Innopush project, which ran at Fraunhofer FHR, everything revolved around semiconductor-based quantum computing under the project name HALQ. Fraunhofer IPMS was in charge of the project. Although there are already various approaches to quantum computing, there are currently only a few realizations in Germany that go beyond the laboratory setup. This gap was to be closed by the project: The goal was to develop an overarching platform that could be used to evaluate and integrate qubit concepts. One of the questions was how the models for the electronic circuits change when they are operated not at room temperature or moderate temperatures, but at four degrees Kelvin - just above absolute zero.

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Business Unit Defense

Fraunhofer FHR's Unit Defense offers great expertise in radar technologies, which are readily used by the Federal Armed Forces and the defense industry.

- Radar is a key technology in defense issues – traditional applications include airspace surveillance and remote imaging reconnaissance. Here, the Business Unit Defense supports the Federal Armed Forces, among others, with its expertise.
- Radar technologies can also be useful at close range, for example for active protection of military vehicles.
- If covert reconnaissance is required, passive radar can be used to detect existing radio waves. The first passive system for air surveillance was developed and commercialized in Germany in the Business Unit Defense.
- Initial results have also been achieved in the area of cognitive radar, which performs its own parameterization.

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.

Air space surveillance and radar imaging for remote reconnaissance

The radar systems developed in the Business Unit Defense monitor airspace from the ground – the radar systems look from the ground into the air. Attached to aircraft or satellites, radar systems monitor air, sea and land areas. Using remote imaging reconnaissance, buildings and other static objects can be surveyed, as can moving objects such as cars. Target classes are also detected: In the air helicopters, missiles and the like are distinguished; on the ground, vehicle classes can be recognized, for example. A general trend that is starting to emerge in the radar field: The use of higher frequencies is increasing. This means that smaller and lighter radar systems can be realized, and the increasing use of mobile communications and WLAN is also making the current frequency range more constricted. With its 300-gigahertz radar, the Business Unit Defense is in the big league on an international level.

Further radar developments for defense

Radar is also a practical solution for some close range issues: It can be important on drones or other unmanned aerial objects, as well as on robots or on vehicles. On military vehicles, it is possible to recognize when the vehicle is being fired on: For example, if a grenade is approaching, the hundredths of a second are crucial to initiate active protection measures.

If another country wants to reconnoiter the conditions in this country, this is by no means welcome. For this reason, the Business Unit Defense is working on deceiving and 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 observation and to thus protect against these types of jamming attempts. This involves not transmitting the signals oneself, but using the radio waves of others to monitor the airspace – in such a way that one does not make oneself noticed. The market launch of such a system for monitoring the airspace of wind turbines in the Business Unit Human and Environment was successful.

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. In the future, the radar will use its own intelligence to set its own parameters and adapt them optimally to the task. After all, it makes a big difference whether radar images are to be taken of areas with high mountains or over the sea with strong waves. Good results have already been achieved in the field of such a cognitive radar, which have also been transferred to industry. Fraunhofer FHR is also already applying its accumulated know-how in the still quite fresh research field of metamaterial design in initial projects for targeted radar backscatter reduction.

Radar system for frequency space monitoring and intentional interference with foreign systems.

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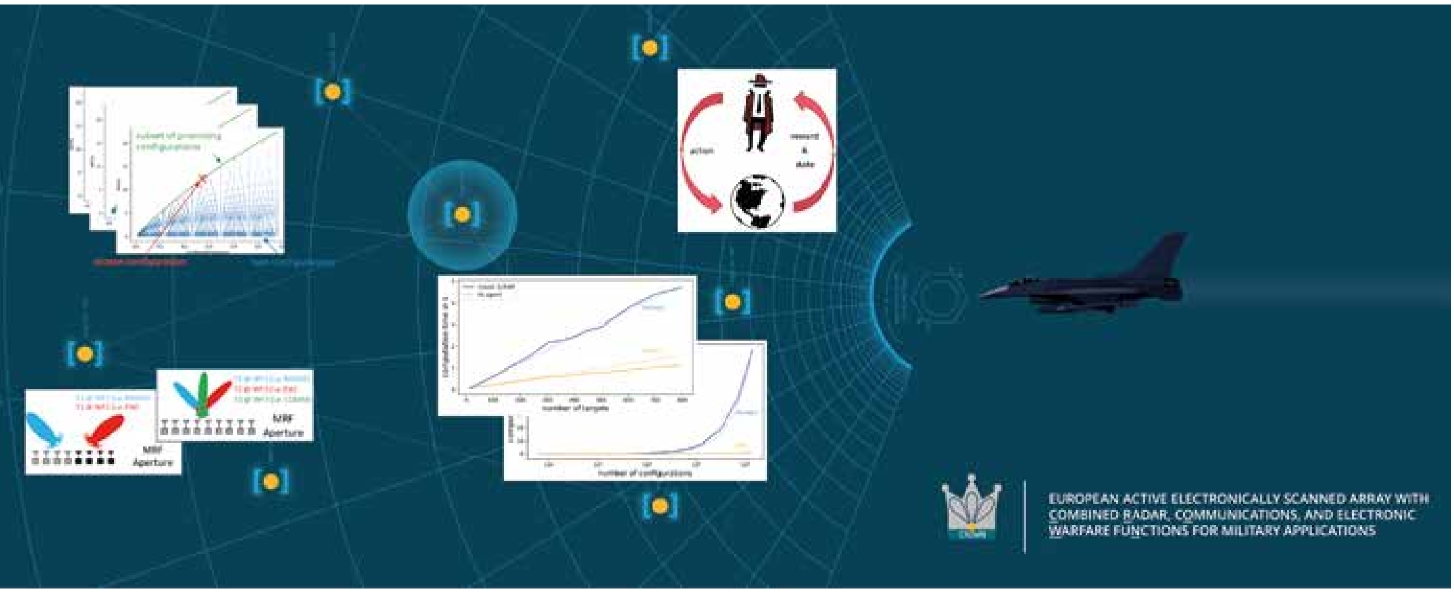
Radar plus electronic warfare



CROWN verwendet maschinelle Lernverfahren, um verschiedene RF-Funktionen in zukünftigen Luftverteidigungssystemen zu vereinen.

Simultaneously generating SAR images, communicating with the ground station and jamming the enemy – this is what a novel air defence system currently being developed by Fraunhofer FHR in cooperation with various European industrial and research partners is supposed to make possible.

A jack of all trades device – in other words, a system that can take on several functions at once? Researchers at Fraunhofer FHR are working on such a system on behalf of the European Commission under the Preparatory Action on Defence Research (PADR) 2019, together with ten European partners from industry and research institutions. In the CROWN project, short for »European active electronically scanned array with Combined Radar, cOmmunications, and electronic Warfare fuNctions for military applications,« they have been developing an RF system that can perform radar functions as well as communications and electronic warfare. So far, this is unique – at least in Europe. In the future, the system could be attached to a drone or integrated into the »Future Combat Air System FCAS« and simultaneously use radar to create situational awareness, communicate with friendly platforms and jam the enemy. In order to be independent of other countries, all the parts needed for this are to come from Europe – which is currently still a challenge. The first major milestone the international research team hopes to achieve this year is to show what resources would be needed to make this happens.

The researchers at Fraunhofer FHR are responsible for resource management, among other things. After all, modern RF systems are supposed to take on many tasks, some of them simultaneously. This can be accompanied by time-related problems, and the energy supply can also be a challenge. For example, it makes little sense to search for new targets in the airspace if the system already can't keep up with tracking the known targets. For starters, the team of experts is working to develop methods that allow the antenna to be divided into several small antennas, known as sub-apertures, that operate in parallel. Then, however, pre-established rules are no longer sufficient to let the system make sensible decisions. The researchers therefore use reinforcement learning methods, a special form of machine learning: They give the system feedbacks on decisions they have made and, in this way, teach it to constantly improve. Another challenge that Fraunhofer FHR is addressing is the realisation of different waveforms of the signals. This is to prevent the signals emitted by the sub-apertures from interfering with each other.

By the end of 2023, according to the plan, the European team would like to raise its development to Technology Readiness Level TRL 4, i.e., to the demonstrator level. A follow-up project will then aim to reach a TRL of 7, equivalent to a prototype.

Coordinator

- INDRA SISTEMAS S.A. (Spanien)

Industrial Partners

- THALES (France)
- ONERA (France)
- HENSOLDT (Germany)
- SAAB AB (Sweden)
- LEONARDO S.P.A (Italy)
- ELETTRONICA S.P.A (Italy)

Universities and Technology Centers

- FRAUNHOFER INSTITUTE FOR HIGH FREQUENCY PHYSICS AND RADAR TECHNIQUES (GERMANY)
- TOTALFORSVARETS FORSKNINGSINSTITUT, FOI (Sweden)
- TNO (Netherlands)
- BALTIC INSTITUTE OF ADVANCED TECHNOLOGY (Lithuania)

EUROPEAN DEFENCE AGENCY

This project has received funding from the European Union's Preparatory Action on Defence Research under grant agreement No 882407 [CROWN].

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Passive radar via satellite signal

Fraunhofer FHR is currently developing a different kind of passive radar with its SABBIA 2.0 system: Instead of using terrestrial transmitters for illumination, it looks at the signals transmitted by geostationary satellites. It can also do its work from moving platforms such as ships.

Usually, radar uses signals transmitted by the radar system itself. However, these signals can also be seen by enemy systems. Passive radar is more inconspicuous: it uses external illuminators, such as radio signals that are already available in the air. Researchers at Fraunhofer FHR are now taking this a step further: instead of using terrestrial illuminators, they are relying on signals from geostationary satellites broadcast for television stations with the SABBIA 2.0 system. The advantages: For one thing, these signals are available in areas where terrestrial signals are poor, such as offshore. For another, the signals have a wider bandwidth and thus a higher range resolution. There is currently no other system in the world that can process such a wide range of signals as SABBIA 2.0.

Passive radars on moving platforms

SABBIA 2.0 offers another special feature: The radar can be mounted on a moving platform, such as a ship – its own movement is compensated. The basis for this is a satellite receiver from the German company EPAK GmbH, which has two antennas. One of these antennas always looks in the direction of the satellite, one in the direction of the target. This is because, as is usual with passive radar: in order to be able to detect a target,

left:
The SABBIA 2.0 system mounted on a rotating platform.

right:
The SABBIA 2.0 system recording a drone signature.

a cross-correlation between the direct signal and the echo of the target is necessary.

A first step in the direction of classification has already been taken: the various backscatter mechanisms can be decoupled via the resolution and further information can be generated from this. A test run is currently being carried out on the premises of Fraunhofer FHR. The radar system is mounted on a rotating platform with a diameter of six meters and keeps a fixed target in its sights, such as a truck. Measurements on a ship are scheduled to follow in the year 2022. The frequencies at which SABBIA operates are significantly higher than those of common passive radar – the system is therefore more sensitive to the Doppler and micro-Doppler effects, in which objects such as drones and sub-objects such as rotor blades move, respectively.

Detecting and classifying drones is therefore also an interesting area of application for SABBIA 2.0. In the future, the system could also use the signals from the nearly 42,000 Starlink satellites that Elon Musk wants to launch into space.

Sabbia 2.0 in Numbers

Bandwidth:

- 600 MHz for multiple polarizations, 1.2 GHz for a single polarization

Range resolution (equivalent monostatic):

- 0.5 meters with multiple polarizations, 0.25 meters with a single polarization

Frequencies of usable satellite signals:

- 10,7-12,75 GHz

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»Eagle-eye radar«: Fastest change of line of sight during overflight

High-resolution images even though the radar and target are moving? Rapid changes in the direction of view? A new type of radar is supposed to make it possible.

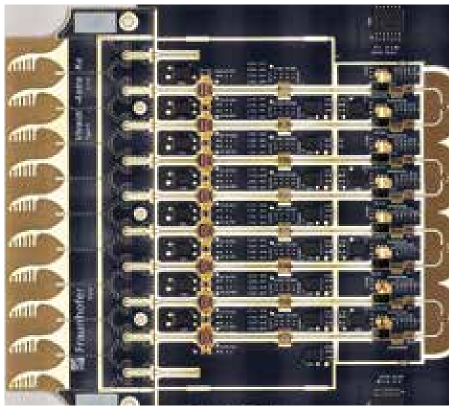
An eagle achieves a very high resolution with its eye – even in flight it can keep an excellent eye on the ground conditions and interpret them extremely quickly. Researchers at Fraunhofer FHR are currently working on a technical reproduction of this performance: With a radar device that – attached to an aircraft – can not only observe the ground rigidly, but also has an agile field of view with high three-dimensional resolution, just like the bird of prey. It should be able to change its angle of view quickly to take a closer look at interesting scenarios. In the future, an algorithm that is also being developed will decide which scenarios are of interest.

High resolution and simultaneous change of viewing direction

The goal: A multifunctional radar that can scan ground scenes with high resolution, detect moving targets within, track them with high accuracy and, to this end, swivel transmit and receive beams within microseconds and with extreme precision. While conventional radars for ground observation mainly operate in the X band, the researchers are relying on the Ka band for the new radar, whose frequencies are about a factor of four higher than in the X band. To do this, they are combining a synthetic aperture radar, or SAR, with the capability of moving target detection and tracking (GMTI). This requires high system bandwidths: because only these enable high resolution in imaging modes of operation – even now, the ground resolutions achieved are less than two centimeters by two centimeters. One challenge: Particularly in the case of changes in the direction of view – which, after all, constitute an agile field of view – quality losses occur with high signal bandwidths, whereby the radar beam deviates from its actual direction of view. This is also referred to as frequency-dependent phase distortion or squint effects. New methods in hardware development can prevent these unwanted effects. The corresponding components of the radar system, especially in the antenna front end, must be designed that inertia-free, electronic 2D beam steering is possible – i. e. the beam can be steered both horizontally and vertically with maximum accuracy. The researchers thus want to ensure distortion-free signal propagation in the various directions. Further challenges lie in optimizing the signal-to-noise ratio and the range to be achieved – the research team is also optimizing these points as part of the project.

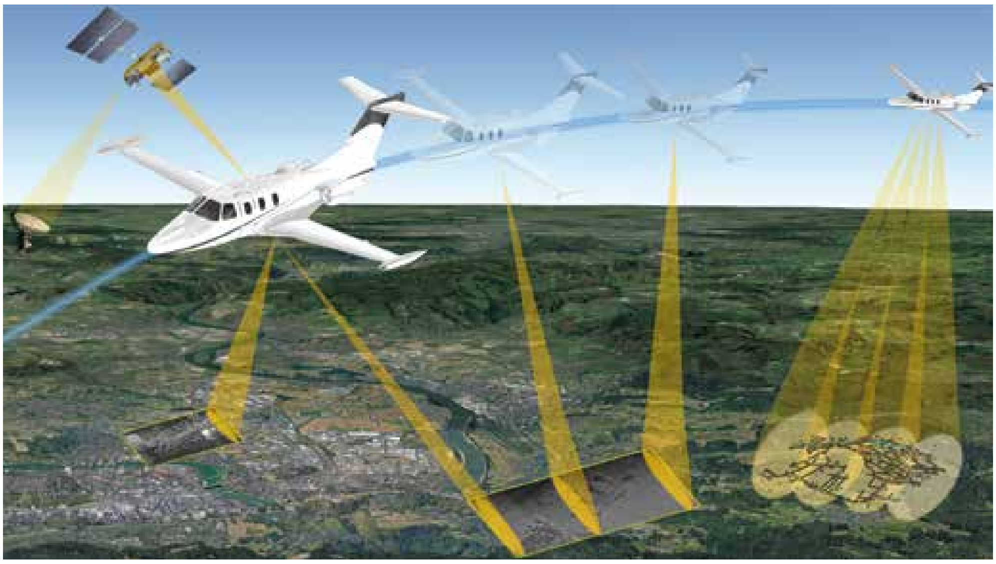
Small and light

Another aspect – and the intention why the radar operates in Ka band: Classic X band radars are comparatively large. Ka band allows for smaller and lighter antennas and sensors. The size of the antenna aperture – the area that radiates energy into the surrounding space – can be reduced by 90 percent by switching from the X band to the Ka band. This is especially important when using the multifunctional radar sensors on small moving airborne platforms such as light aircraft and drones, or in the future in formations of airborne platforms that swarm to observe scenarios from different directions. In addition, the research team is working to match the dimensions of the rest of the system (backend) to the downsized antenna aperture.



top:
Antenna measurement of high bandwidth Ka-band antennas in an anechoic chamber.

bottom:
Multifunctional radar electronics suitable for compact assemblies.



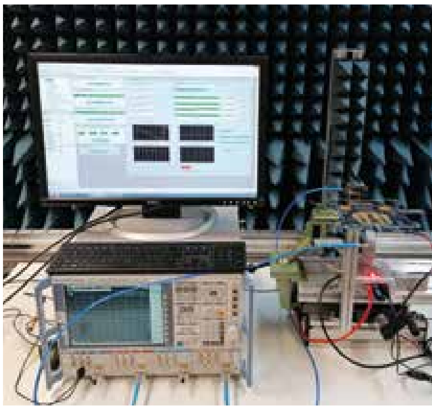
Multifunctional airborne radar with agile change of view direction for motion target detection-GMTI (right), high-resolution SAR modes (center r. and center l.), high data rate communication (left) - Artist View.

This primarily requires a compact design of the electronics. Among other things, this also raises questions of heat generation and thermal management – after all, heat is dissipated more poorly from small volumes. Appropriate concepts for this are also being investigated in the project.

Fundamental to such volume reduction are integrated high-frequency chips for the Ka band and compact design techniques – while simultaneously increasing performance. A particular challenge lies in the increased free-space attenuation for signal propagation in the Ka band compared to that in the X band, which reduces the range of the radar for the same system performance. How can this be maintained at similar levels? This is where the reduced-volume sensor technology comes into play again: since more antenna elements can be accommodated in a smaller area, the radiated power per area increases – which helps compensate for the loss in terms of range. In addition, the significantly increased reflectivity of ground structures during illumination with Ka band signal energy also helps increase the distance between the target area and the radar. On the technical side, the researchers have already developed the prototypes of the system's array modules, and the test environments have also been realized. They are currently working on the construction of a phased array demonstrator, and the next step will be the serial production of the front-end components.

Interesting also for communication

As far as applications are concerned, the new radar is particularly suitable for aerial reconnaissance of ground conditions – after all, the focus is on an imaging application due to its high resolution capability. But the researchers are also keeping an eye on other applications: For example, the type of electronic beam direction control can also be used for communication systems. This is particularly interesting for future electronically slewing broadband antennas that ensure broadband communication between the ground station and satellites. Or also for communication of an aircraft with the ground station, for example via a satellite link: Via compact electronics installed in the fuselage, for example, a combined communications and radar system of the aircraft would have alternating views of various satellites distributed across the sky – again, very rapid changes in the angle of view are always required. Agile changes of viewing direction of the observation antennas are also required when the airspace is to be monitored from the ground. One possible scenario is drone radar to increase security at an airport. The investigations being carried out by the research team in the project are providing the groundwork for novel applications of radars for and with communications tasks.



Calibration of transmitter modules for the Ka band phased array.

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3D printed antenna: High complexity – simply manufactured

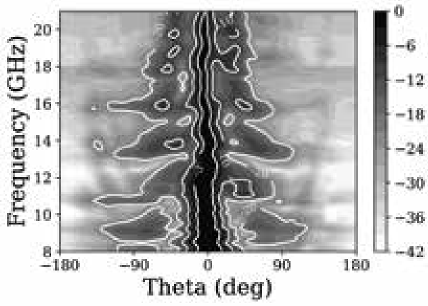
High-performance radar systems on board of unmanned aircraft as well as in vehicles of all kinds require systems that are as light and compact as possible. With this in mind, researchers at Fraunhofer FHR are developing radar-compatible 3D-printed waveguide-based antenna array systems that are significantly more compact and easier to manufacture than their metal-based counterparts.

Be it defense, satellite, medical or automotive applications, the next generation of radars will require more bandwidth, range and power – which can only be achieved with highly complex solutions – while being lightweight, compact and cost-effective. Sounds hardly feasible? So far, this impression has been pressing: After all, waveguide-based antenna arrays usually consist of many small and heavy parts normally made of metal, which are also extremely complex to manufacture and hence cost-intensive.

3D printing technology offers a way out. Researchers at Fraunhofer FHR are relying on it to develop new waveguide antenna array designs consisting of several radiating elements with high bandwidth. The array comes from the 3D printer and is made of plastic – the resulting antenna arrays are therefore much lighter than their metal counterparts. Another highlight is that despite the complex structure, the antenna can be manufactured in just one step, which makes production much more easy and cost-effective. By using 3D printing technology, more compact waveguide antenna array designs can also be realized without sacrificing system efficiency.

Since the plastic itself does not have the electromagnetic properties required by an antenna, the researchers galvanize it with a layer of copper and nickel. The unique properties of the developed process allow the metallization layer to be applied only to the outer surface – further simplifying the manufacturing process and eliminating the need to deal with the inside parts of the structure. The applied copper layer allows the electromagnetic phenomenon to occur, while the nickel stabilizes this layer and protects it from oxidation and corrosion. The result is already impressive: The 3D-printed antenna, which operates in a frequency range of 8 GHz to 21 GHz and has a directivity of 17 dBi, has already been successfully tested at Fraunhofer FHR.

Currently, researchers at FHR are looking forward to enhancing the performance of the 3D printed structures by investigating novel manufacturing approaches and testing new materials to apply to their designs.



top:
Prototype manufactured using 3D printing technology and metal-coated by galvanization (total volume 8x8x9 cm³).

below:
Measurement results showing the co-polar radiation pattern in the theta plane compared to frequency. Color scale in dB.

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Bundled knowledge: Materials for high-frequency applications

Even in the information age, it is sometimes not easy to obtain the data you need: For example, the electromagnetic material parameters needed for antennas in high-frequency technology. A web-based catalog is to provide these parameters from a single source for the first time.

The range of materials that can be used for applications in high-frequency technology is wide: various magnetic, dielectric, conductive and absorbing materials come into consideration. Each one has its own unique material parameters. Especially for simulations of antenna structures, feeding networks and platforms for high-frequency applications, these parameters must be known exactly, otherwise the simulation results would not be very accurate. Another difficulty is that the material parameters change with frequency - sometimes more, sometimes less, depending on the material. Only limited information about the electromagnetic behavior of materials can be found in simulation tools, publications and data sheets. Information on new materials is hardly available at the moment. In addition, only a few key values are usually given for each material - for given parameters at lower frequencies, only extrapolation remains, which can, however, deviate greatly from reality. The same applies to the behavior of the materials at varying temperatures.

Measurement of parameters at Fraunhofer FHR

At Fraunhofer FHR there is the possibility to measure the characteristic parameters of the individual materials, with different setups and in different frequency ranges. However, such measurements are a time-consuming and cost-intensive undertaking: First, the device has to be calibrated, then the setup has to be validated with further material before the material can be measured several times to estimate the measurement uncertainty.

Web-based catalog

For the first time, the researchers at Fraunhofer FHR are compiling all the parameters determined, including the measurement uncertainty, in a web-based catalog - the project will run until mid-2024. The basic framework of the database is already in place, as is the prototype of a web interface. The parameters of 15 materials have also already been added, and the trend is steadily upward. Currently, the database is still running on a test server; in the coming months, it will be made accessible to the entire Fraunhofer FHR. Researchers will then be able, among other things, to compare materials with each other or search specifically for materials with certain characteristic values. In a further step, metamaterials will also be included in the catalog: Material compositions that cause wave effects due to their special composition. Other candidates for the database are 3D-printed materials. Here, the parameters are to be specified both for the raw material and for the printed material - depending on the printer type as well as the process parameters. In the long term, it is conceivable to make the platform available to the European market.

Web interface of the material database. This is where Material characteristics can be viewed or downloaded.

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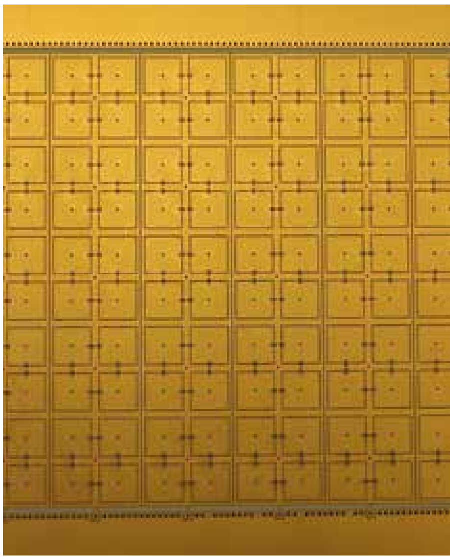
Extended scanning range for array antennas

The scanning range of array antennas is physically limited. It could be extended in the long term by electronically tunable metamaterials.

Product developers want as much freedom as possible in development and design. In contrast to conventional materials, the properties and frequency characteristics of metamaterials can be adjusted by the developers themselves – even values that do not occur in nature are possible. For example, materials can be manufactured in which waves cannot propagate in certain frequency ranges. This is because metamaterials consist of periodic subwavelength unit cells that are produced using printed circuit board technology or 3D printing.

Metamaterials provide a further degree of freedom in the development of antennas, among other things: They can be used, for example, to realize specific shielding properties or wave absorption characteristics. But how can military radar systems be improved using metamaterials? Fraunhofer FHR is investigating this together with the Spanish company Tafco Metawireless S.L. and the Universidad Pública de Navarra, also in Spain, in the METALESA II project for the European Defence Agency. Fraunhofer FHR is focusing on array antennas, which consist of a set of antenna elements and whose radiating surface is curved. Usually, the beam direction of such antennas is adjusted electronically, but the beam scanning range is very limited. Using electronically tunable metamaterials, it is hoped, it may be possible to extend this scanning range. The electromagnetic properties of these special metamaterial structures can be locally adjusted by applying DC voltages to the varactor diodes integrated into the metamaterial unit cells. While the research team in the previous METAFORE project had already conducted an extensive literature research and made technology predictions, as well as introducing one-dimensional transmission line metamaterials and metamaterials designed to suppress parasitic surface waves of specific wavelengths on array antenna apertures in METALESA I, it is now working with electronically tunable metamaterials. The researchers have already successfully measured smaller circuit boards from Fraunhofer FHR to characterize tunable metasurface structures in a test setup, and now larger boards are to follow.

In further steps, the Fraunhofer FHR research team will address the challenges that currently still exist when combining antennas and metamaterials. For example, the bandwidth of antennas should be as large as possible – but the resonance effect of the metamaterials has so far stood in the way of this. In addition, the antenna still loses too much of its gain when the signal penetrates the metamaterials.



The metasurface is electronically tunable – it is intended to increase the scanning range of conformal array antennas.

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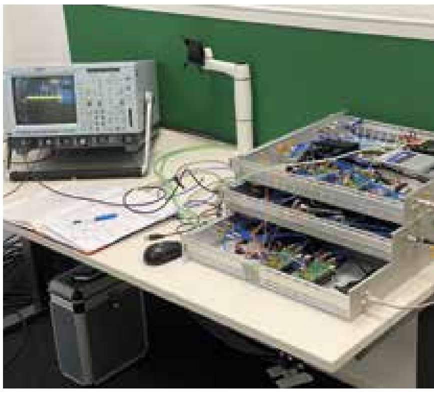
Multistatic radar: Timing alternative in case of disturbed GPS reception

People around the world rely on GPS signals – but they are susceptible to manipulation. Researchers at Fraunhofer FHR are developing a timing alternative for multistatic radar.

Without navigation software, many people would be stuck – especially in foreign cities, people are glad to rely on the friendly voice that shows them the way. Even outside of private navigation, the world is dependent on GPS signals and satellite navigation, as they provide very accurate data on position and time. There is also a »but«: GPS signals are very easy to interfere with and switch off – this is called jamming – or to manipulate so that the system thinks it is in a different place. GPS alone is therefore not reliable, especially for critical operations. However, there is still a lack of alternatives.

Researchers at Fraunhofer FHR are working on such alternatives: The problem occurs with multistatic radar. Here, the transmitting and receiving stations are located in different places, for example on two buildings or on moving platforms such as ships, aircraft or drones. The advantage of multistatic radar over conventional radar is that the different locations can provide more information, for example, stealth aircraft can be detected. The effect is comparable to human eyes, which allow spatial vision through their different positions. Multistatic radar is also more robust against enemy interference and countermeasures and more sensitive to small targets. But it is also much more complex: Above all, times and frequencies must be synchronized – to within a few nanoseconds, sometimes even sub-nanoseconds. In addition, the distance between the platforms must be known precisely. As far as static platforms are concerned, this is not a major problem. However, it becomes difficult with moving platforms. To determine the distance between the two moving radar systems and synchronize their clocks with each other, a master clock sends its time to one or more slave clocks via two-way time transmission technology. Thus, a peer-to-peer solution is being developed in which the platforms synchronize in a closed system. A third-party system such as a ground base station is unnecessary.

What is needed now is a test environment to validate and develop this idea. Strapping the systems onto two aircraft is far beyond the budget, and the effort is also far too high. The researchers have therefore created an alternative: they connect the two clocks, which should actually be on two moving platforms, with copper cables, while an algorithm tricks the systems to think they are moving. In this way, the team has the ability to study moving platforms while they are actually standing still in the lab. In the long term, the team plans to include relativistic effects on this platform. It is also working on implementing navigation via broadcast signals, i. e., using a passive approach.



Adaptive teaming clock network under test – all random platform trajectories are simulated.

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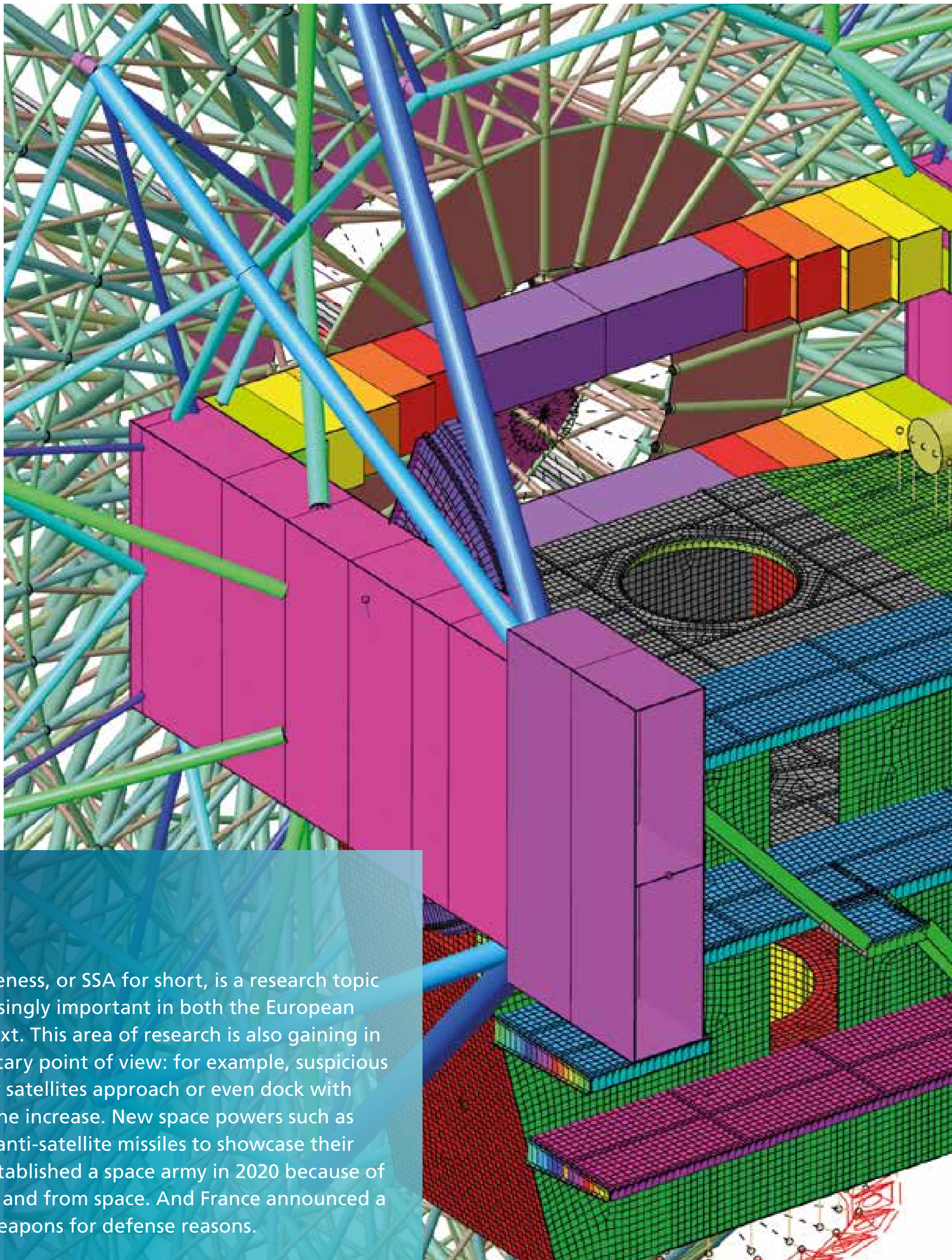

Business Unit Space

Space Situational Awareness, or SSA for short, is a research topic that is becoming increasingly important in both the European and international context. This area of research is also gaining in significance from a military point of view: for example, suspicious maneuvers in which spy satellites approach or even dock with other satellites are on the increase. New space powers such as India and China tested anti-satellite missiles to showcase their capabilities. The U.S. established a space army in 2020 because of the increasing threat in and from space. And France announced a plan to develop laser weapons for defense reasons.

- The density of satellites and space debris in low-Earth orbit is increasing rapidly. This involves increasing hazards.
- Fraunhofer FHR's Business Unit Space's TIRA and GESTRA radar systems can be used to monitor, observe and identify objects in low-Earth orbit. The two systems complement each other in an optimal way.
- The GESTRA radar system, which was developed for the German Space Agency at DLR, can acquire the orbital data of numerous objects very quickly and across a large section of space at the same time.
- If an object is to be detected and imaged more precisely, the TIRA radar system is a good choice.

Space: Precise detection of the position of object

It is not only on roads in metropolitan areas that traffic density is high. Low-Earth orbit is also very busy and sometimes crowded: It is littered with active satellites as well as space debris – their density is increasing rapidly.

This rush hour in space is accompanied by increasing hazards: collisions can destroy satellites and affect infrastructure that is important to society (e.g., navigation or communication satellites). It is therefore essential to detect, monitor and track space objects: If these are always in view, countermeasures can be initiated in good time in the event of imminent danger, such as evasive maneuvers by satellites.

GESTRA and TIRA: Hand in Hand

The radar systems researched and developed by Fraunhofer FHR's Business Unit Space are ideally suited for monitoring, observing and identifying objects in low-Earth orbit. In this context, the two radar systems TIRA and GESTRA complement each other perfectly. The GESTRA radar system, which was developed on behalf of the German Space Agency at DLR (German Aerospace Center), allows continuous monitoring in wide-range space – it can be used to determine the orbital data of many objects simultaneously. In addition, GESTRA can be used to determine the altitude of objects as well as their inclination – the degree between the Earth's equator and their orbit. Another special feature: GESTRA combines phased array antennas, mechanical mobility of the radar units in three axes, and mobility of the entire system. GESTRA can thus be deployed at any location, enabling a network of radar systems for space surveillance.

If, on the other hand, a specific satellite or other space object needs to be detected more precisely, TIRA is the system of choice. It allows satellites to be detected and imaged with much greater precision – and additionally enables statements to be made about the satellite itself. If a satellite is not working, for example, TIRA can be used to clarify whether this may be due to the solar panel not being deployed correctly. The ability to image space objects in high definition using TIRA is unique in Europe, which is why the system has already supported numerous missions.

To date, the Business Unit Space has been focusing on the space situational awareness of space objects. The plan is to expand Earth-based SSA sensors to include a space-based radar. In this case, the radar system that observes the space objects is no longer located on Earth, rather on a satellite in orbit. The portfolio is also to be expanded with the inclusion of other research topics such as active antenna technologies for communications satellites, SAR (Synthetic Aperture Radar) technology for Earth observation satellites and satellite-based microwave radiometers for climate and environmental research. The Business Unit Space will therefore be even more broadly positioned – the major competencies will then also benefit other space research fields.

With the help of a rodwork model, the moving part of the TIRA space observation radar was remodeled on the basis of around 400 original drawings. With the approximately 150000 nodal points thus obtained, the load distribution of the new imaging radar to be developed can be precisely determined. This ensures that the loads of the new radar system are distributed in such a way that there are no static impairments to the system.

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Detect space debris better with higher transmitting power

The increasing amount of space debris is becoming more and more dangerous for active objects in space. An accurate catalogue of the debris particles orbiting the Earth enables satellites to avoid collisions. The space surveillance radar GESTRA, which was developed by Fraunhofer FHR, contributes to this catalogue. An additional transmitter unit shall now furthermore increase the detection performance of the GESTRA network, allowing it to detect even smaller debris particles.

When thinking of outer space, most people probably have an empty and infinitely wide space in mind. The low Earth orbit, however, is not that empty any more: It contains more than a million inactive objects – space debris that can no longer be controlled. Active satellites circling around in space therefore almost have to complete an obstacle course.

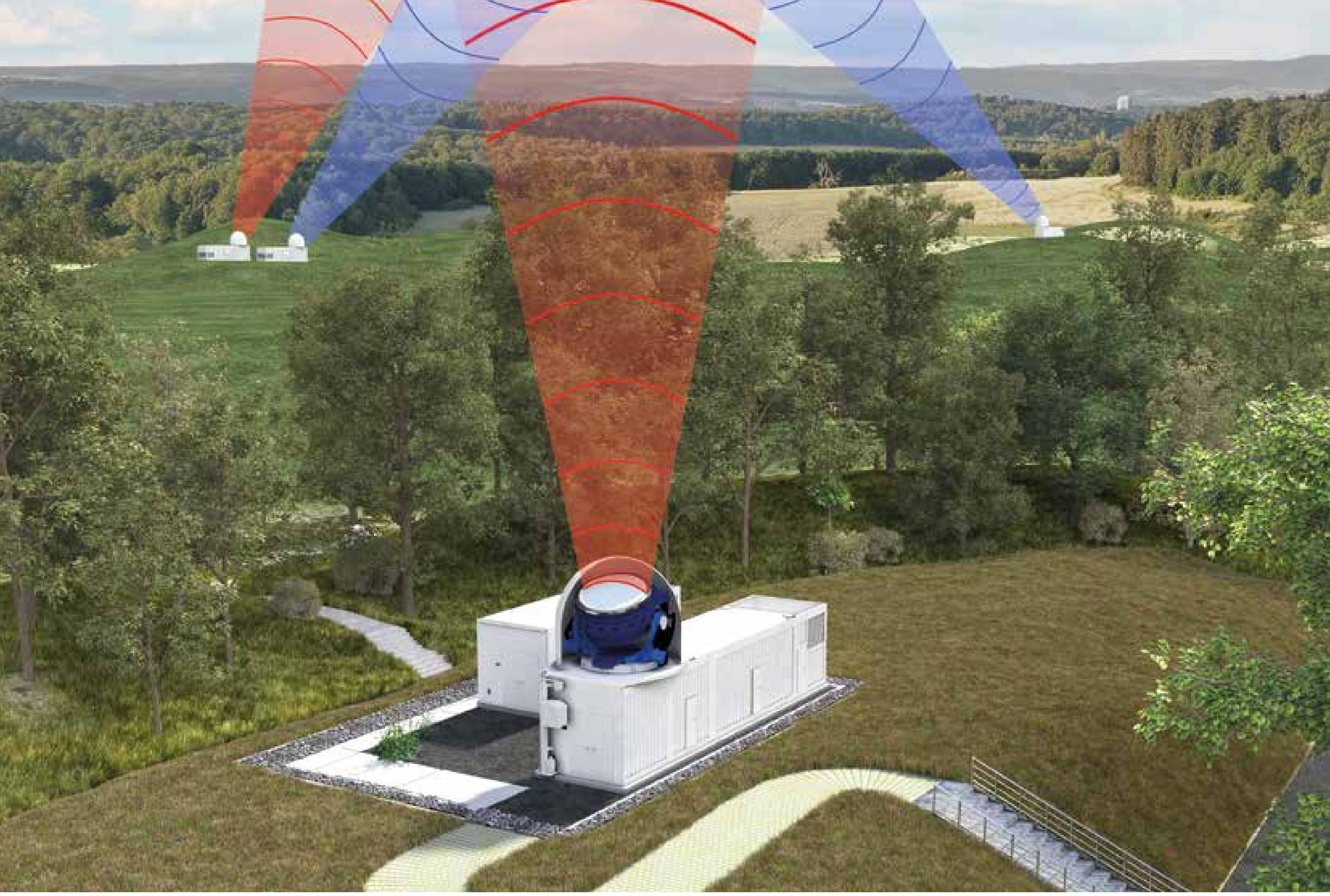
The GESTRA space surveillance radar helps to detect and catalogue the various objects in a large section of space, so satellites can fly evasive maneuvers if necessary. More specifically, it is a quasi-monostatic system, a phased array radar with high range and beam agility, consisting of separate transmit and receive systems. In 2020, the GESTRA EUSST project for another receiver was commissioned at Fraunhofer FHR. On December 1, 2021, Fraunhofer FHR researchers started building an additional GESTRA-compatible transmitter unit in the GESTRA TX2 project. It will use a different transistor technology and be twice as powerful as the current transmitter. Thus, when GESTRA is combined with the new system, the transmitting power will increase by a factor of three. This leads to different improvements: On one hand, the range will increase, i.e. the system can see further into orbit. On the other hand, and more importantly, it allows much smaller debris to be detected. The interconnected system could then observe junk parts only a third the size of those GESTRA can detect on its own. A special feature: All departments of Fraunhofer FHR are involved in the development – seven in total plus research groups. The Fraunhofer institutes IWU and IPM provide additional support for the development of an innovative cooling technology for the planks.

Development of an antenna concept

The first goal of the project is to create a concept for the transmitting antenna. This concept includes two PCB prototypes. The first one consists of the transmitting module, which shall have an increased power: This will be realized by a multistage amplifier chain with high power amplifiers connected in parallel. The module will be completely redeveloped, including all the necessary monitoring functions – in other words, the vital parameters of the system. The GESTRA single antenna element also has to be optimized: Can the GESTRA concept be operated with twice the transmission power? Does this require a new development of the antenna element and possibly also of the antenna array? These questions must be answered in the first period of the project.

The second prototype is the circuit board that generates the transmit signal in a decentralized manner. The researchers are redesigning the entire signal generation concept. While in the GESTRA system an RF signal is generated at one point and distributed to all antenna elements, in the TX2 system an individual signal will be generated for each transmitting module. How can these decentralized signals be kept synchronized? This approach is new territory – it has only been done in a few projects so far. Initial ideas are already available.

right:
Radar network for space surveillance: The new GESTRA TX2 transmitter (foreground) in combination with GESTRA EUSST receiver and GESTRA system.



Networked operation

It is essential that receivers and transmitters must be able to be operated in a network – after all, the aim is to interconnect the GESTRA, GESTRA EUSST and GESTRA TX2 systems to form a network. The systems do not necessarily have to be located next to each other, but can be several hundred kilometers apart. The second objective of the first project period is therefore a feasibility analysis for networked operation with multiple transmitter systems.

The project will initially run for two years: At the end of this period, a proof of concept is to be produced, in other words, a proof that the approach works in general. Based on this concept, the German Aerospace Center DLR has the option to commission the design and construction of the transmit system.

Project Key Facts

Project start: 1.12.2021

Project end period 1: 30.11.2023

Project duration and costs:

- Period 1 (concept): 24 months with 5.6 million €.
- OPTION
  - Period 2 (design): another 12 months with approx. 12.5 million €
  - Period 3 (construction): another 36 months with approx. 30.88 million €.

Project team (Period 1): approx. 45 employees

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Despite all expectations

The European satellite ENVISAT lost contact with Earth in 2012. Since then, it has been spinning in a popular orbit – with decreasing rotational speed, as the scientific community assumed. But measurements by Fraunhofer FHR show that it has been spinning faster and faster again since 2018.

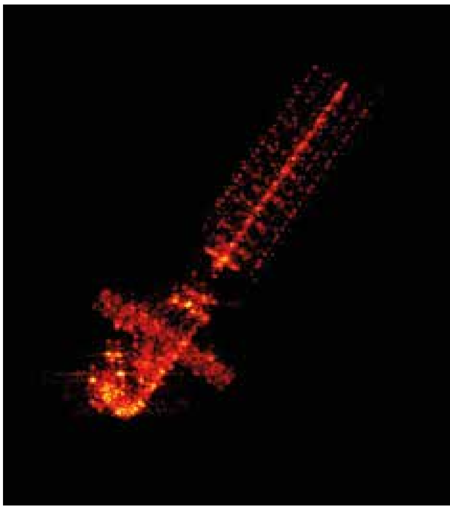
How are the climate, oceans and land areas, or more precisely the Earth's ecosystem, changing? This was to be monitored by the European satellite ENVISAT, which was launched into space by ESA in 2002. At a total cost of 2.3 billion euros, it was ESA's most expensive satellite to that date and the largest Earth observation satellite ever launched into orbit. For more than ten years, it performed its service as intended, but in 2012 contact was lost. Since then, ENVISAT has been whirring uncontrolled through space as junk. What led to the loss of contact remains unexplained. Subsequent investigations, however, revealed an interesting fact: The satellite began to rotate, and at an accelerating rate. In 2013, however, the rotation speed decreased again. Experts agreed that this trend would continue in the future.

With ENVISAT, ESA has not only lost an expensive satellite but also created one of the statistically most dangerous debris: While the first 20 places in the ranking are occupied by rockets, ENVISAT, which weighs about eight tons, is right at the top of the list of satellites at number 21. This is more difficult because it currently orbits at an altitude of 765 kilometers – in a sun-synchronized orbit in which an extremely large number of satellites are bustling around. However, in order to be able to grab ENVISAT with another satellite and move it out of the way, its rotation speed must be known precisely.

The predictions do not hold!

But – this is what researchers at Fraunhofer FHR discovered in 2019 during sporadic measurements: the predictions of the steadily decreasing rotation speed do not apply. Measurement campaigns in 2020 and 2021 confirmed the surprising result: the rotation is actually getting faster again. At the beginning of 2013, the satellite was spinning at its fastest, at about three degrees per second. Thus, the satellite needed 120 seconds for one rotation. In 2018, it was only spinning at half speed, with a full 240 seconds elapsing during one rotation. In the first half of 2021, however, it managed to do so in just 210 seconds – a significant difference. Since then, the satellite has been steadily accelerating.

The researchers used the TIRA radar system for their investigations. When the satellite appears on the horizon and flies overhead in the sky, the L band target tracking radar tracks it until it disappears from sight after ten to 15 minutes. During the tracking, the Ku band radar acquires data for imaging. With the data collected, the researchers created ISAR images, short for »Inverse Synthetic Aperture Radar.« In this process, two physical quantities create an image plane: first, the round trip time of the transmitted radar pulses, and second, the Doppler shift induced by the object's own rotation. In order to scale the images correctly – and to be able to calculate the rotation speed over a longer period of time – the researchers take advantage of the fact that they know the geometry and size of the satellite. By assigning individual points of this 3D model to points in the ISAR images, they can calculate the intrinsic rotation of the satellite – and in turn convert the measured Doppler frequencies into a length. In other words, they project the 3D model onto the ISAR images and thus obtain correctly scaled images.



top:
Artist view of the environmental satellite ENVISAT.

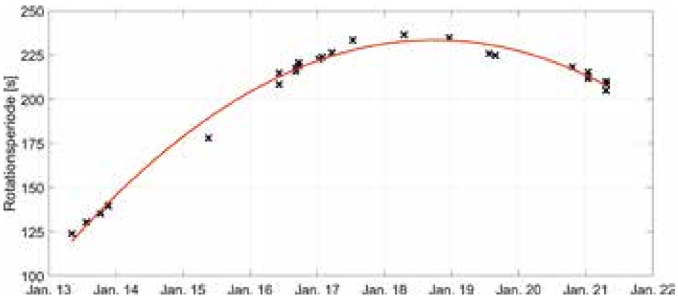
bottom:
ISAR radar image from the Envisat satellite.

But what caused ENVISAT to lose contact with the Earth and start spinning?

This question cannot (yet) be answered. Usually satellites are stabilized with flywheels. Could the energy of these flywheels have been transferred to the satellite by friction effects? Probably not, because this would not explain the high rotation speed. It is also unclear why the rotation slowed down again. Maybe this can be traced back to eddy current induced by the Earth's magnetic field in the satellite? Also, the Earth's gravity could be affecting the satellite's axis of rotation. Another possibility lies in the Yarkovsky-O'Keefe-Radzievskii paddack effect. This originally refers to asteroids – their rotational properties are altered by thermal radiation from the sun.

The researchers at Fraunhofer FHR have now tried to track down the cause of the renewed increase in rotational speed: They investigated whether a connection could be found with solar activities since 2018, for example with eruptions on the solar surface. But here, too, no cause could be found. What is certain, however, is that the satellite is spinning faster again – and the cause is still being tracked down.

Time course of the satellite's rotation period: Since 2018, it has been rotating faster again.



Tracking and Imaging Radar (TIRA)

- Experimental radar system
- Type: 34m parabolic antenna in Cassegrain configuration
- Mass: 240 t
- Mechanical positioning accuracy: 0.6« (0.000172°)
- Weather protection: 47.5 m radome
- currently 2 integrated radars (Tracking Radar, Imaging Radar)

Tracking Radar

- Target tracking of space objects
- L frequency band: 1.33 GHz
- 3 dB Lobe width: 0.49
- Lobe width at 1,000 km distance: 8.6 km
- Detection sensitivity at 1,000 km distance: 2 cm

Imaging Radar

- Target imaging of space objects
- Ku frequency band: 16.7 GHz
- 3 dB Lobe width: 0.031°
- Lobe width at a distance of 1,000 km: 0.54 km

Applications of TIRA

- High-precision orbit determination in support of missions and close encounter predictions
- Temporal and spatial predictions of re-entries
- Damage and fragmentation analysis of satellites / rocket upper stages
- Object identification and classification
- Observation and (statistical) analysis of the space debris environment

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Business Unit Security

In general, security research is based on three major pillars. First: The protection of people – whether at major events or at railroads and airports – and their rescue, for example in the event of 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 supplies or communications. Third: Protection against crime and terrorism. How, for example, can we counter the fact that more and more people are carrying knives on the street and using them in banal disputes? In Berlin alone, for example, there are about a dozen knife attacks – every day!

- The attack on the World Trade Center on September 11, 2001, led to numerous national and international research programs designed to protect civilians in peacetime.
- Radar offers numerous opportunities across all pillars of security research to enhance civilian security.
- For example, drones combined with radar technology can locate human life signs in smoke-filled buildings or under rubble.

Civil security: Wide-ranging support from radar

9/11 struck fear into the world as the first terrorist-motivated attack of this dimension on a civilian target. It was followed by attacks in Madrid in 2004 and London in 2005.

In response to the attacks, research programs were launched to address the protection of the civilian population in times of peace. One such program is the German federal government's security research program »Research for Civil Security.« Radar offers numerous opportunities to enhance civil security.

Protection and rescue of people: Unmanned systems with radar sensors

In the event of a disaster, it is often difficult for emergency forces to obtain an accurate picture of the situation in the shortest possible time. It is extremely dangerous to enter burning buildings in search of people. Drones combined with radar technology can be a great help here: Drones could, in principle, fly into smoke-filled buildings and locate signs of life via radar sensors attached to them. At the same time, radar sensors can ensure that drones navigate safely through buildings. This would allow rescue missions to be carried out much more quickly, efficiently and safely. Radar sensors can also locate signs of life under rubble. In the future, it would be conceivable to allow drones to operate autonomously – this would provide further relief to for human rescue workers. The Business Unit Security is already researching radar technologies for this purpose.

Cognitive radar goes one step further, with the radar system independently setting the optimum parameters for the current situation.

Critical infrastructure protection: Inspection robots equipped with radar sensors.

Civil security also includes detecting the smallest cracks in cooling towers of power plants, tunnel systems, bridges or similar infrastructure. Drones and robots can also take on these sometimes dangerous and time-consuming tasks. There are two starting points for radar technology here: First, it can prevent collisions via sense and avoid. If the radar sensor registers a wall or other obstacle, the data can be sent to the controller of the drone or robot so that they avoid the obstacle. The Business Unit Security has already successfully completed initial tests on this. Secondly, radar sensors offer advantages in analyzing infrastructures - for example, they can map structures with millimeter precision even in dark, smoky and inaccessible environments and detect the finest cracks and damage.

Protection against crime

Radar systems can also be of great help in protecting against crime. They enable security forces to detect without contact whether people are carrying knives or other dangerous objects hidden under their clothing.

Networkable radar modules for human localization – project Lupe+ funded by the German Federal Ministry of Education and Research.

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Facing floods and other disasters

The floods in the Ahr Valley showed that climate change is making itself felt much faster and more strongly than expected. Therefore, approaches to mitigate the consequences of climate change must also be more radical than planned. The team of the Innopush project »RuLe – Resilience of Urban Living Spaces« reacted promptly and adapted the research to the current conditions.

In the summer, heavy rain caused the Ahr and other streams to burst their banks at record speed – sweeping away bridges, houses, trucks and cars and leaving a picture of devastation in their wake. Entire village communities lost their roof over their heads and had to camp in gymnasiums or on the guest couches of relatives and acquaintances; numerous people even lost their lives. This is where the Rule project, short for »Resilience of Urban Living Spaces,« comes in. In this interdisciplinary project, researchers from Fraunhofer FHR and the Fraunhofer Institutes IMS, LBF, IML, FKIE, INT and IAO are investigating just such catastrophes to find out how to emerge stronger from them. The focus was on the »tunnel fire« and »heavy rainfall« scenarios. How can sensors be used to provide helpful information – for example, on the presence and movement of people or the current performance of the drainage system – that cannot yet be captured purely by sensors? The researchers distinguished between three phases: Before the event, the event itself and the subsequent reconstruction of the infrastructure, which should be as resilient as possible.

The flood disaster showed the limits of previous technology

Due to the current situation, the Fraunhofer Institutes also provided acute assistance to the emergency services: Fraunhofer FHR installed radar sensors at the Steinbach Dam, which was in danger of bursting, to measure the stability of the dam, and Fraunhofer FKIE provided support with regard to the management infrastructure, such as situation imaging. However, the disaster situation also made visible where improvements must be made in the future: for example, numerous technical early warning and control systems have been undermined. One example is the radar level sensors that have been installed on bridges in recent years: Here, there is a small antenna on a cantilever arm that measures the levels of the streams and thus allows forecasts of flooding. Usually this works very well – but only as long as the water flows under the bridge and the bridge exists. However, during the Ahr flood, which more than doubled the previous peak, many stationary measuring stations were lost. The catastrophic situation may well serve as an example for future floods – a glimpse into the crystal ball, so to speak, of what challenges cities and communities will have to face in 2050 or 2060.

RuLe adapted the research to the circumstances

So what can be learned from this disaster for the future? The researchers in the RuLe project also asked themselves this question and developed corresponding solution concepts. For example, instead of using stationary platforms for warning systems, research is increasingly focusing on mobile systems – such as drone-operated or wearable sensors

Tunnel fire: A special hazard situation.

Heavy rain event: Dernau (Ahrweiler district) a few days after the flood disaster in the Ahr valley.

that monitor the stability of buildings during damage events. The Ahr Valley also showed that the use of satellite communication worked very well. This will play an increasingly important role in future rescue systems worldwide. These and comparable disasters show that the expert teams at the Fraunhofer institutes must constantly adapt their research to the rapidly changing environmental conditions. The question of how to provide rescue workers with information about the locations of immobile people – ad hoc and in line with data protection requirements – also takes on a whole new significance in this context.

Another focus besides heavy rain events was the »tunnel fire« scenario. Here, too, the project team demonstrated new system approaches that have not yet been implemented in urban environments, or have only been implemented in rudimentary form – for example, in the area of sensor technology, the detection of people and their movements. In both scenarios, the researchers looked not only at individual technologies or a specific problem, but at the entire chain – from planning to technical solutions to individual processes. RuLe was thus able to respond very flexibly to the challenges of heavy rain events or tunnel fires.

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Business Unit Traffic

The Business Unit Traffic has high-quality technical equipment at its pulse as well as employees with a profound understanding of physics who are well versed in the mobility industry and extremely familiar with current challenges and issues. Therefore, even challenging issues can be solved profitably and individually tailored to the customer.

- Autonomous driving is a major future trend that, starting from the roads, is increasingly spreading to rail and shipping as well as aviation.
- Radar is the key sensor for more autonomy on road and rail, on water and in the air. After all, the safety of all road users must be guaranteed at all times.
- The Transport Business Area offers in-depth and broad-based scientific expertise in all aspects of radar, supplemented by knowledge of the industry.

Radar systems for greater safety in cars, planes, trains and ships

Safety is elementary in autonomous driving. Radar sensors are tailor-made for this task: Unlike optical sensors, they work day and night and in all weather conditions – even in dense fog.

The business unit Traffic of Fraunhofer FHR offers a deep and broad scientific expertise in terms of radar: from high-frequency systems and signal processing to classification of objects and electromagnetic simulations.

On the road...

Today, radar sensors are already installed in cars almost as standard to support the driver. Here, too, the Business Unit Traffic has already contributed its expertise: special radar antennas from Fraunhofer FHR, for example, have already been installed 30 million times in 100 different types of vehicles. The current focus is primarily on miniaturizing the systems and developing conformal antennas – i. e. antennas that can be adapted to the geometry of the car and thus fit well into the available installation space. Other current research approaches in the Traffic Business Unit are concerned with the question of how radar waves interact with different materials. This is important, for example, if the radar sensor is to be installed behind the company logo or bumper so that it is invisible to the user. In a test environment, newly developed sensors are put through their paces by simulation. Using our simulation software GOPOSim, various moving objects such as cars, bicycles, pedestrians can be integrated into the different street scenes.

...on water, in the air and on rails

At the moment, the business field is strongly characterized by applications in the automotive sector. However, the level of autonomy is also increasing in other areas of traffic – with the corresponding requirements for sensor technologies. For this reason, the business unit Traffic has already made important contributions to the development of several radar sensors for shipping and air traffic. One example from the field of shipping: The innovative SEERAD sea rescue system makes it possible to locate shipwrecked persons at a distance of six kilometers with a radar transmission power of only 100 watts – a world record. In the field of aviation, Fraunhofer FHR has developed, among other things, a landing assistance system for helicopters. This assists the pilot during landing maneuvers when swirling dust obscures the view.

As far as activities in rail transport are concerned, these are to be further expanded in the future – because hardly any solutions are available on the market here yet. The Traffic business unit aims to close this gap. There are numerous applications for radar systems in rail transport: For example, the sensors could analyze track beds, detect cracks in tunnel walls, measure track gauges and address similar issues.

A completely new radar reflector system developed at Fraunhofer FHR, in which the reflection occurs at exactly the same angle as can be seen in a visual calibration mark. Conventional radar reflectors consisting of three orthogonal plates, so-called corner reflectors, are unsuitable for this purpose due to their depth. The combination of visual calibration mark and reflector must function at relatively short distances, such as in laboratories, on production lines or in repair shops.

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LIDAR system with encanced environment perception

Autonomous vehicles need various sensors that serve as their »eyes«, so to say. Indispensable here are LIDAR systems that produce good images even in the dark. A new frequency-modulated LIDAR system combines a long range with good resolution and is also cost-effective, small and energy-efficient.

If cars and other vehicles are to purr autonomously through cities and streets in the future, they will need appropriate sensors to do so. In particular, LIDAR, short for »light detection and ranging«, is likely to be indispensable here due to its high resolution. This method generates images that are similar to those of an optical camera and can be used to distinguish pedestrians, cyclists and other road users. Unlike visual systems, they can do this not only in broad daylight, but also in pitch darkness. What's more, modern LIDAR sensors are able to accurately measure the distance, angle and height of objects and even their speed with much less computing power – so they can provide greater safety and efficiency on the road. Typically, however, the range of LIDAR systems comes at the expense of resolution: while long-range LIDAR systems can look far but have low resolution, it's the other way around for short-range systems.

High resolution, long view

In the collaborative Fraunhofer PREPARE project MELINDA, Fraunhofer FHR, Fraunhofer ISIT and Fraunhofer HHI are developing a fiber-based 2D-microelectromechanical scanning LIDAR system that scores both with a long range of up to 250 meters and with a high horizontal and vertical resolution of 0.1 degrees. The system thus combines the advantages of long- and short-range LIDARs. It is also cost-effective, compact and energy-efficient. Another special feature is that the LIDAR system developed uses frequency-modulated illumination and a special coherent detector that mixes the signal reflected back from the object with that from the coherent laser. In this way, both amplitude and phase information can be used – so the result is not only more accurate distance information, but also data on the speed of the objects seen.

Fraunhofer FHR is dedicated to the reconstruction of dense depth maps from sparsely scanned scenarios: instead of illuminating all points in the field of view, this LIDAR system deliberately leaves numerous gaps – this allows the scanning speed to be significantly increased, which is extremely important for recognizing dynamic road scenes. Naturally, the resulting point clouds are also full of gaps. The missing points are reconstructed as best as possible using appropriate data processing, more specifically compressed sensing and deep learning methods. With success: Five percent of the pixels are sufficient to reconstruct an image – so instead of 10000 pixels, 500 are enough! The research team is currently working on the development of a demonstrator of the LIDAR system.

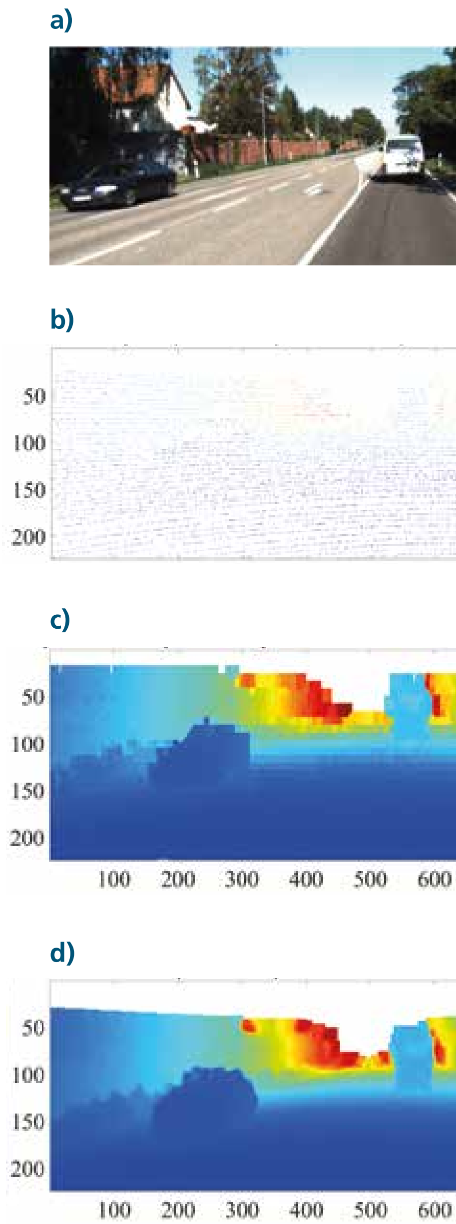

Fig. a) RGB reference image of a selected snapshot from the KITTI dataset, b)considered point cloud after 50% data reduction, and obtained dense depth maps c) using CS (BPDN) and d) Deep Learning (SICNN).

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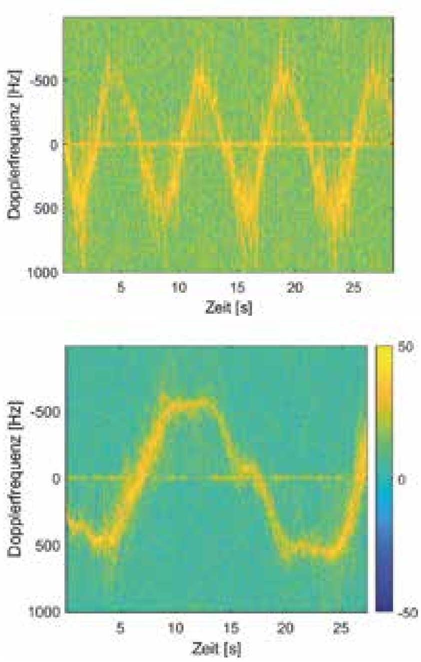
Cyclists and pedestrians – optimally protected

Making dangerous intersections safer and providing the best possible protection for pedestrians and cyclists: This is the goal pursued by four Fraunhofer institutes in the »Konsens« project. To achieve this, they merged the data from permanently installed radar and infrared sensors.

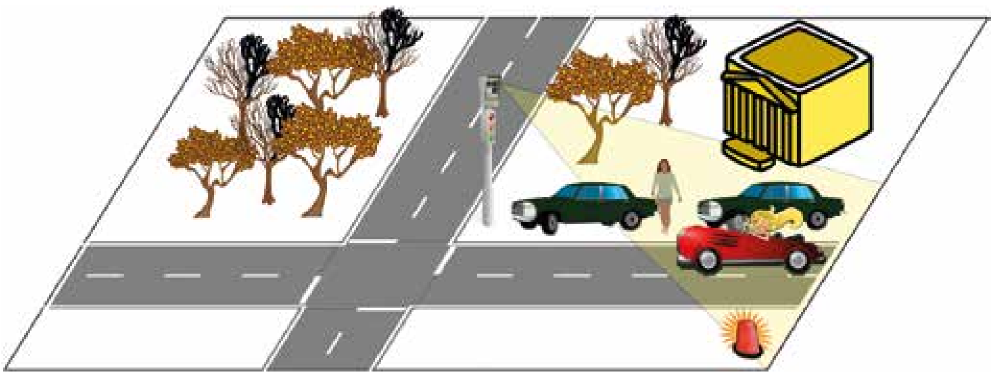
Yet another dicey situation at the intersection where accidents occur repeatedly: A pedestrian walks between parked cars and wants to cross the street – the view on the traffic comes too late. In the future, sensors in traffic light poles, or comparable installations, could provide better safety at dangerous intersections. If, for example, a person walks between parked cars towards the road, the sensors will detect the pedestrian and send warnings to the vehicles in the vicinity. Such infrastructure sensors could also provide useful support for autonomous driving in the long term. Intelligent intersections are also conceivable: For example, if the road is clear and a pedestrian approaches the intersection, the pedestrian lights could switch directly to green.

Researchers from Fraunhofer FHR and the Fraunhofer Institutes IAIS, IVI and IIS worked on the corresponding sensors in the »Konsens« project, which ran as a successor project to »HORIS« from January to July 2021. The main attraction here is the combination of infrared and radar. While infrared sensors are very good at detecting how far to the right or left a pedestrian or cyclist is moving in the image, they have difficulties measuring distance. However, this is where radar sensors show their strength: They can measure distance precisely, but have greater uncertainties when it comes to determining right-left. Both together give a perfect combination for the problem at hand. Neural networks perform the classification – distinguishing whether an object is a pedestrian or a cyclist – independently for the data from the infrared and radar sensors. In the case of the radar data, this is done via the movements of the persons: In the case of a pedestrian, the periodic pendulum motion of arms and legs can be seen; in the case of the cyclist, on the other hand, the echos of the rotating spokes as well as the pedaling motion can be detected. Both the results from the infrared data and those from the radar data are given with a certain confidence, e.g. »With a probability of 98 percent, it is a pedestrian.« The result that provides the higher level of confidence is used by the system.

In the long term, the number of objects that are classified can be expanded to include typical road users – for example, electric scooters could be considered in addition to pedestrians and cyclists.



top:
Comparison of radar data of a pedestrian (top) and a cyclist (bottom).



left:
A person walks between two cars towards the road.

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Business Unit Production

If something goes wrong with production processes in industry, this quickly results in high costs. While some questions in production monitoring can already be answered satisfactorily by camera or laser systems, other production processes require sensors whose capabilities go beyond those of optical systems: Fraunhofer FHR's Production business unit offers the necessary expertise for all radar-related issues.

- Radar sensors can also monitor production processes where optical systems reach their limits: For example, in rolling mills where very high temperatures prevail and a lot of steam and slag is generated.
- In addition, radar sensors offer the possibility of non-destructively inspecting products – whether in food inspection, plastic components of all kinds or composite materials.
- The Production business unit offers the necessary expertise as well as the technical equipment to lead individual questions from industrial partners to success.

Production processes always in view

Companies have a great interest in monitoring their production processes. Radar sensors can not only measure under difficult environmental conditions where visibility is limited, for example, but can also see through dielectric materials and detect defects there.

Non-destructive testing for food, plastics and composites

Taking a look inside objects without destroying them: Radar makes this possible, at least for dielectric materials. In food testing, for example, foreign substances can be detected in the product. Radar is also promising in the non-destructive testing of additively manufactured components, i. e. plastic parts from the 3D printer.

Radar testing also offers advantages during the life cycle of a product. For example, in the case of composite materials, such as the blades of wind turbines. To this end, among other things, FHR is developing imaging algorithms for high-resolution millimeter-wave radar scans at 60 GHz for monitoring fiber optic systems in fiber composite manufacturing in the FiberRadar project funded by the ERDF Lead Market Agency NRW. Promising results have already been achieved here with FHR's broadband radar technology at 80 and 220 GHz. FHR's fully integrated SiGe chip solution at 220 GHz achieves unprecedented image resolution, making fiber layers and material defects clearly visible. For greater penetration depths, multiple frequency bands will be fused.

Inspecting production processes for metals

One interesting area of application for radar systems is rolling mills in the steel industry. In general, the earlier defects are detected, the less expensive they are to repair. If a car door has a dent, it is initially easy to sort it out. However, every further production step costs money. Often, sheet metal for car doors is still inspected visually for defects. With a millimeter wave sensor, even the smallest scratches can be reliably detected. In the long term, it would even be possible to achieve 100 percent inspection in this way.

Future trends Smart Factory and additive manufacturing

In the smart factory, both the supply of components and production are to proceed intelligently and autonomously. However, autonomy starts with the sensors: Here, the Production business unit offers the necessary expertise. Individual solutions can also be developed for safety-critical aspects such as machine safeguarding.

With the production of components in the 3D printer, antennas can be printed, for example, or component concepts can be realized that could not be produced in this way before. Together with high-frequency technology, new fields of application are opening up: For example, antennas could be integrated directly into functional components of the production machine by making the component function like an antenna where it is penetrated by the radar wave.

3D metal printer with a build volume of 250mm x 250mm x 325mm for example aluminum, stainless steel, nickel alloy and copper.

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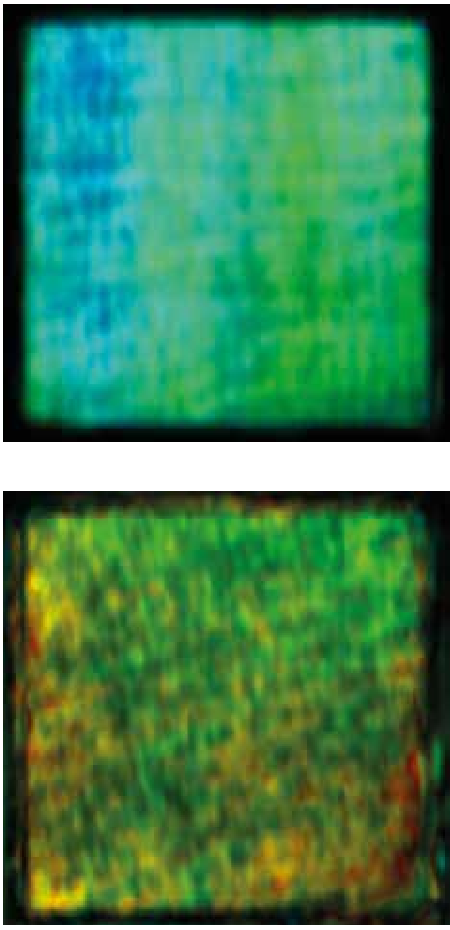
Investigating fiber composite materials fully automatically

A new method for fully polarimetric radar allows fiber composite materials, for example for wind turbines, to be examined – automatically, non-destructively and throughout the entire volume.

Wind turbine rotor blades are largely made of glass fiber-reinforced plastics. During production, various glass fiber mats are placed on top of each other, placed under vacuum and bonded with a matrix element – usually a resin. No mistakes must be made when laying out the glass fibers, otherwise the quality of the later component could suffer. Are the individual glass fibers correctly aligned? Are there unwanted ondulations, i. e. waves in the glass fibers? Up to now, this has been checked manually, but only the top layer can be detected. Questions about the alignment of the glass fibers can therefore so far only be answered to a limited extent, if at all.

In the publicly funded project Fiberradar (NRW-Leitmarkt), researchers at Fraunhofer FHR, together with Aeroconcept GmbH, Ruhr University Bochum and Aachen University of Applied Sciences, are now developing a method that for the first time can also be used to check the alignment of the lower layers – non-destructively and automatically. A fully polarimetric radar makes it possible. The special feature: While conventional radars have only one channel and thus use only one polarization for transmission as well as for reception, the new radar sends out signals in two polarizations, and the receivers also work with two polarizations. Taken together, therefore, four possible combinations can be used to collect information. When these four images are combined, they can be used to determine the direction of the fiber layers and to detect alignment errors. In contrast to conventional radar images, the research team does not obtain a black-and-white image here, but a colored one in which the individual colors represent different reflective behaviors. Refraction compensation improves the image quality even further: it eliminates inaccuracies caused by refraction effects, especially in deeper layers. By imaging the individual layers with the radar, the researchers can check the entire volume of the material non-destructively.

The radar, developed by Ruhr University Bochum, is currently being put through its paces on Fraunhofer FHR's test platform: The team is examining samples from Aeroconcept, in which the orientation of the glass fiber layers changes with depth. The goal of the project is to attach the system to the arm of a robot that moves automatically through the production hall and scans the produced components.



Decomposition method applied to a fiber layer 3mm (top) and 6mm (bottom) below the surface.

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Recycling plastics: Via MIMO sensor technology

Plastics contain a lot of carbon, but currently only about a quarter of it is kept in the cycle. In the Waste4Future project, seven Fraunhofer institutes are working on technologies to boost the recycling of plastics.

The numbers are staggering: 12 million tons of plastic are consumed in Germany every year, produced almost always from fossil raw materials. Their production releases around 49 megatons of carbon dioxide into the air. Only just under half of the waste containing plastic – 6.3 million metric tons annually – is materially recycled; 53 percent is incinerated. Yet the carbon contained in plastic is an important resource for the chemical industry.

In the Fraunhofer lead project Waste4Future, researchers from Fraunhofer FHR are working with six other Fraunhofer institutes to keep plastics and carbon in the cycle as much as possible and to increase the industry's security of supply with sustainable platform chemicals. In other words, to be able to increase recycling in the long term. At the same time, this reduces the need for fossil resources, CO2 emissions and plastic waste pollution. The principle: A new type of sorting system identifies which materials and, in particular, which plastic fractions are contained in the waste. Which path makes the most sense technologically, ecologically and economically for which waste?

To this end, Fraunhofer FHR is developing a scalable MIMO radar sensor that includes 32 channels and operates in the G band. It is designed to characterize the waste that passes under it on a belt. Since it is to be a dual-band sensor in the final stage of development, it will not only transmit frequencies from 120 to 160 gigahertz, for example, but also frequencies from 220 to 260 gigahertz simultaneoulsy. In this way, it generates added value about the structure and properties of the material stream. For example, it should not only be able to analyze black plastics, but also enable statements to be made about the aging state of the plastics. The data collected is analyzed by Fraunhofer IZFP using appropriate signal processing and machine learning. The silicon germanium chip for the MIMO sensor is also being developed at Fraunhofer FHR. The challenge here is that it must function not only in one, but in two frequency bands. To do this, an onboard chip antenna for higher frequencies and an external antenna must be combined – due to the spatial distance between the two antennas, this is a complex task both technologically and algorithmically. The developed methods are interesting not only for the chemical and plastics processing industries, but also for companies in waste management, recycling plant construction and recycling plant operation.

8-channel high-frequency module in the W band of Fraunhofer FHR integrated in the bulk material sorter »Tablesort« of Fraunhofer IOSB

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Business unit Human and Environment

Where does the use of radar around people make sense? In general, wherever geometric and kinematic quantities need to be measured, i. e. where the shape and movement of an object need to be analyzed.

- Radar systems are becoming increasingly smaller and less expensive, and are thus moving much closer to people.
- One of the possibilities here: Radar can determine, through clothing, breathing and pulse rates of people – whether in the medical field, fitness or elderly care.
- Radar also enables contactless human-machine communication in environments where optical systems reach their limits.
- Radar also offers many advantages in the environmental field, for example in increasing efficiency in agriculture.
- The Human and Environment Business Unit offers the necessary expertise in all these areas.

Radar: For Human and Environment

Radar technology is becoming smaller and cheaper – and is now reaching a level of miniaturization that is bringing it increasingly close to humans.

Radar for humans

One example is the monitoring of vital parameters such as respiration and pulse rate: radar measures the movement of the chest, from which the respiration rate is deduced. The pulse rate is derived from the movement of the skin – as in case of scanners at the airport through the clothing. This makes sense, for example, for newborns in hospitals or in elderly care, in sleep laboratories or in the fitness sector. A lot of research work is still needed for signal processing in this attractive field: Fraunhofer FHR is ideally positioned for this.

Radar is also suitable for other motion analysis problems, be it the motion analysis in sports or in a rehabilitation center. For example, Fraunhofer FHR is working with partners to research how to detect relieving postures after an accident.

Radar for communication

In the field of communication, human-machine interactions are of particular interest. For example, smartphones often already have an integrated radar sensor. The advantage is that the sensor recognizes gestures even through clothing. For example, a user can accept a call by gesture without taking the phone out of his or her jacket pocket. This also helps in occupational safety: Instead of having to press small buttons with thick work gloves, machines can be controlled with gestures and hand signals. This makes sense in areas where textile-penetrating gestures are necessary or the work environment is characterized by fumes and steam, for example.

Radar for the environment

Precision farming uses modern technologies to increase the efficiency of agriculture. Radar is tailor-made for this task: It is harmless to humans, animals and plants and allows not only imaging of leaves and stems, but also examination of roots. It thus allows plant penetrating analyses. Detection of wildlife and vital signs monitoring of farm animals is also an exciting field where radar technology can open up new possibilities.

In the wake of climate change, weather radar, along with weather forecasts based on it, are also becoming increasingly important. While these are established techniques, there is still much room for improvement. Here, the Human and Environment business unit is pursuing many ideas – because the technological leaps that have been achieved in the area of radar can also be used for weather radar.

The environment area also includes a red-flashing warning light on wind turbines that alerts aircraft pilots. In many areas, however, aircraft are the exception. The ParaSol radar developed in the Human and Environment business unit detects approaching aircraft and allows the flashing light to be switched on only when necessary. The system has already been approved by German air traffic control.

Radar sensors can be used to monitor patients' vital signs.

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Vital signs of Corona patients at a glance anytime

If the condition of a person infected with corona deteriorates, rapid action is required – such as artificial respiration. In the future, a new sensor network could help doctors to keep a constant eye on the condition of their patients and to react immediately if their condition deteriorates.

If a person is infected with the Corona virus, critical situations can quickly arise. Medical staff therefore always want to know: How does the condition of infected persons change? Is there a need for action, for example because a lung is no longer being properly ventilated? In the future, sensors developed by ten Fraunhofer Institutes and four medical partners under the leadership of Fraunhofer IIS in the M3Infekt project - Fraunhofer FHR was also involved – could provide information about such questions. Various sensors are to monitor the vital parameters of patients and, when combined, ensure universal monitoring: In this way, changes in condition can be detected at an early stage and appropriate countermeasures can be initiated quickly.

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Radar sensor measures vital data without contact

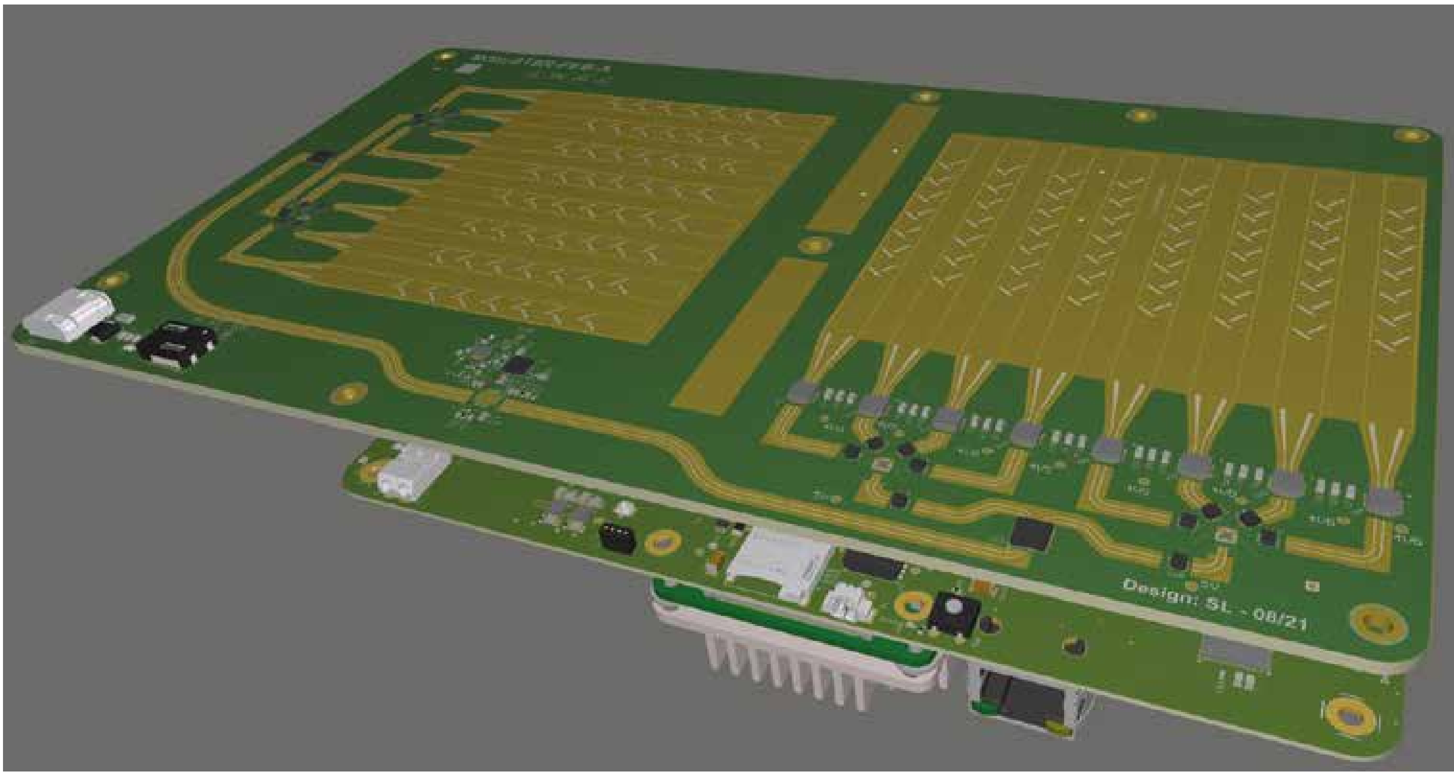
A wristband measures pulse and oxygen, a vest checks respiratory volume and determines whether the lungs are sufficiently ventilated, a chest strap creates a continuous mini ECG and an optical camera system determines vital parameters. In addition, there are radar sensors from Fraunhofer FHR: the flagship is a multi-channel MIMO sensor, short for »Multiple Input Multiple Output«. Hanging in the corner of a room, it measures the vital signs of the people in the room – especially their breathing rate. To monitor the condition of individual patients, the researchers developed a single-channel sensor to complement the portfolio. Beyond measuring vital signs, the radar sensors also enable tracking of the person in the room. To make the results even more robust and generate added value, the data from the radar sensors is combined with that from the optical camera system from Fraunhofer IIS/EAS. For example, how is the person facing the sensor – does he have his back turned away?

Principle of the MIMO sensor

The MIMO radar sensor has a total of eight transmitting and eight receiving channels. The signals sent out by a transmitter module are reflected by the various objects in the field of view – by the bed and table as well as by the ill person – and received by the eight receiver modules. Since these are spatially slightly separated from each other, the signals arrive at the various receiving channels at slightly different times. The differences in propagation time make it possible to determine where in the room a corresponding object is located.

*top:
Capture vital signs without contact.*

*bottom:
Housing of the 24G-MIMORAD sensor.*



Board stack consisting of analog front end (top) and digital back end (bottom).

The eight transmitter channels in turn serve to increase the spatial resolution. But how can the vital parameters of patients be measured with radar? The answer: via the movement of the chest during breathing. When a person breathes in, the chest rises by one to two centimeters – a stroke that can be clearly seen in the measurement signals. Even the heartbeat, a much finer movement, can be detected with the radar sensors. Since the heart beats at a much higher rate than our breathing rate, these signals can be easily separated. To be able to separate the vital signs of different people, they must be at a minimum distance from each other: If they are standing more than 60 centimeters apart, the system can resolve their vital signs separately from each other – and even if the persons are standing behind each other as seen from the sensor. This value is due to the bandwidth of the measurement signal: The researchers relied on a free ISM band with a bandwidth of 250 MHz for the system, which meets the guidelines of the German Federal Network Agency.

Clinical study in planning

The MIMO sensor consists mainly of two boards: an analog part, the front end, which generates the signals via a high-frequency circuit. And secondly, the backend, in which the analog measurement signal is digitized by an analog-digital converter and then processed by the algorithm in the form of digital measurement data in the evaluation computer and converted into vital parameters. Both the housing of the MIMO sensor and the digital module already exist, and the algorithm is also ready. The front end, i. e. the analog part, is in progress. In a further step, the researchers want to carry out initial test series at Fraunhofer FHR before evaluating the system in a clinical study on external subjects.

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 2021:

www.fhr.fraunhofer.de/publikationen2021

Publications in scientific journals:

www.fhr.fraunhofer.de/publikationen2021-journals

Publications in scientific conferences:

www.fhr.fraunhofer.de/publikationen2021-konferenzen

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https://publica.fraunhofer.de

Education and Training

Lectures

WS 2020/2021

Brüggenwirth, Stefan: »Kognitive Sensorik«, Ruhr-Universität Bochum (RUB)

Cerutti-Maori, Delphine: »Signal Processing for Radar and Imaging Radar (VO)«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Cerutti-Maori, Delphine: »Signal Processing for Radar and Imaging Radar (UE)«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Heberling, Dirk: »High Frequency Technology - Passive RF Components«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Heberling, Dirk: »Hochfrequenztechnisches Praktikum«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Heberling, Dirk: »Moderne Kommunikationstechnik - EMV für Mensch und Gerät«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Knott, Peter: »Antenna Design for Radar Systems (VO)«, Rheinisch-Westfälische Technische Hochschule Aachen

Knott, Peter: »Antenna Design for Radar Systems (UE)«, Rheinisch-Westfälische Technische Hochschule Aachen

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

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

Pohl, Nils: »Master-Praktikum Schaltungsdesign integrierter Hochfrequenzschaltungen mit CADENCE«, Ruhr-Universität Bochum (RUB)

Pohl, Nils: »Grundlagenpraktikum ETIT«, Ruhr-Universität Bochum (RUB)

SS 2021

Brüggenwirth, Stefan: »Grundlagen der Radartechnik«, Universität der Bundeswehr München

Heberling, Dirk: »Elektromagnetische Felder in IK«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Heberling, Dirk: »High Frequency Technology - Antennas and Wave Propagation«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Knott, Peter: »Radar Systems Design and Applications«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

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

Supervised doctoral studies

Culotta-López, Cosimo: »Fast near-field antenna measurements by application of compressed sensing«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Gisder, Thomas: »Methoden zur Integration eines automobilen Radars mit synthetischer Apertur«, Technische Universität München (TUM)

Hamid, Sofian: »Lossy Dielectric Resonators for Microwave Absorber and Antenna Applications«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Kohler, Michael: »Country-specific ground based Bistatic Radar Clutter analysis of rural environments«, Eberhard Karls Universität Tübingen

Palm, Stefan: »Mapping of urban scenes by single-channel mmW FMCW SAR on circular flight and curved car trajectories«, Technische Universität München (TUM)

Pisciottano, Iole: »Multidimensional passive ISAR for Maritime Target Imaging«, Universität La Sapienza

Schraml, Korbinian: »Breakdown Analysis and Sidelobe Suppression in High Power Feed Antennas«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Thomas, Sven: »Integrierte Schaltungen für die hochpräzise Abstandmessung«, Ruhr-Universität Bochum (RUB)

Supervised master theses

Arumugam, Ram Kishore: Masterarbeit »Development of super-resolution detection algorithms for sparse scenes in presence of clutter«, Technische Hochschule Ingolstadt

Golabian, Somayeh: Masterarbeit »Schaltungsentwurf eines voll differenziellen Operationsverstärkers für integrierte Zwischenfrequenzfilter in einer modernen Sige-Technologie«, Ruhr-Universtät Bochum

Ludwig, Christopher: Masterarbeit »Entwicklung eines 120 GHz MIMO Radarfrontends«, Hochschule Koblenz

Pütz, Stephan: Masterarbeit »Aktive Unterdrückung der reflektierten Leistung (RPC) für gepulste simultane Sende- und Empfangs-Radarsysteme (STAR); Active Reflected Power Cancellation (RPC) for Pulsed Simultaneous Transmission and Receive (STAR) Radar Systems«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Singh, Prabhat: Masterarbeit »An Investigation of Passive Radar using 5G illuminators of opportunity«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Thaker, Anshuman Paresh: Masterarbeit »Adaptive algorithms for drone detection using MIMO radar«, TU Chemitz

Toth, Peter: Masterarbeit »Design and Implementation of an Ultra-Wideband Radar Receiver Operating up to 50 GHz and Frequency Band Characterization in a Cryogenic Environment«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Wegner, Benedikt: Masterarbeit »Evaluierung der Xilinx-SoC Plattform zur Echtzeit-Signalverarbeitung in SAR-Anwendungen«, Hochschule für Technik, Wirtschaft und Kultur Leipzig

Committee Activities

Behrendt, D.

- Deutsche Gesellschaft für Zerstörungsfreie Prüfung (DGZfP): Mitglied

Bertuch, T.

- IEEE Antennas and Propagation Standards WG P145: Mitglied
- European Conference on Antennas and Propagation (EuCAP) 2021: Technical Review Committee
- European Defence Agency (EDA), CapTech Technologies for Components and Modules (TCM), Technology Building Block (TBB) 06 »Enabling Components for Advanced Antennas« Roadmap report editor team: Leiter

Brüggenwirth, S.

- IEEE AESS Germany Chapter: Secretary
- EDA Radar Captech: German Governmental Expert
- European Microwave Week (EuMW) 2021: Technical Review Committee
- IEEE Radar Conference 2021, TPC member
- NATO Science and Technology Organization SET Panel Member at Large for Machine Learning and Artificial Intelligence
- VDE ITG Vorstandsmitglied

Caris, M.

- International Radar Symposium (IRS) 2021: Technical Program Committee

Cerutti-Maori, D.

- Inter-Agency Space Debris Coordination Committee (IADC): Nationale Vertreterin in der Working Group 1 (Measurements)
- IEEE (Institute of Electrical Electronics Engineers): Senior Member

Cristallini, D.

- NATO STO Group SET-242 »PCL on Mobile Platforms« : Co-Chair
- AGERS 2021: Technical Program Member
- EuRad 2021: Technical Program Member
- IEEE RadarConf 2021: Track Chair

Danklmayer, A.

- Deutsche Gesellschaft für Ortung und Navigation (DGON), Vorsitzender des Fachausschusses für RadartechnikVDE-ITG Fachausschuss HF 4 »Ortung«: Vorsitzender
- International Radar Symposium (IRS) 2021: Technical Program Committee
- U.R.S.I. International Union of Radio Science, Commission-F Wave Propagation and Remote Sensing: Member
- NA 131 FK »Förderkreis des DIN-Normenausschusses Luft- und Raumfahrt (NL)«: Mitglied
- DIN Arbeitsausschuss NA 131-01-05 AA für Drohnen-Detektion: Mitarbeiter

Fröhlich, A.

- European Defence Agency (EDA), CapTech »Ad Hoc Working Group Space Defence«: Non-governmental Expert

Heberling, D.

- European Conference on Antennas and Propagation (EuCAP) 2021, Düsseldorf: Mitorganisator, Mitglied des Steering Committee
- European Conference on Antennas and Propagation (EuCAP) 2022, Madrid: Mitorganisator, Exhibiton Chair
- Zentrum für Sensorsysteme (ZESS) 2021, Siegen: Vorsitzender Wissenschaftlicher Beirat
- IMA (Institut für Mikrowellen- und Antennentechnik e. V.): Vorsitzender
- IEEE (Institute of Electrical Electronics Engineers): Senior Member

Klare, J.

- International Radar Symposium (IRS) 2021: Technical Program Committee
- European Microwave Week (EuMW) 2021: Technical Review Committee
- IEEE International Conference on Aerospace Electronics and Remote Sensing Technology (ICARES) 2021: Technical Review Committee
- 8th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI) 2021: Technical Program Committee
- International Conference and Workshop on Telecommunication, Computing, Electrical, Electronics and Control. (TELKOMNIKA) 2021: Review Committee

Knott, P.

- Informationstechnische Gesellschaft (ITG) im VDE, Fachausschuss HF 4 »Ortung«: Vorsitzender
- Deutsche Gesellschaft für Ortung und Navigation (DGON): Mitglied im Wissenschaftlichen Beirat, Vorsitzender Fachausschuss Radartechnik
- NATO Science and Technology Organization SET Panel Member at Large for AESA Radar
- International Radar Symposium (IRS) 2021: Chair

Markiton, P.

- IEEE AESS YP representative 2020-2022
- IEEE AESS QEB Editor-in-Chief 2022-2023

Matthes, D.

- NATO STO Group SCI-332 »RF-based Electronic Attack to Modern Radar« : Chair

Nüßler, D.

- VDI/VDE-GMA FA 8.17 Terahertz-Systeme: Mitglied
- European Machine Vision Association (EMVA): Mitglied

O'Hagan, D.

- NATO STO Group SET-296 »Radar against Hypersonic Threats« : Chair
- NATO STO Group SET-268 »Bi-/Multi-static radar performance evaluation under synchronized conditions« : Chairman
- IEEE AES Magazine: Editor-in-Chief
- IEEE AES Magazine: Associate Editor for Radar
- IEEE Radar Conference: Technical Program Member
- European Defence Agency: CapTech Member
- International Radar Symposium (IRS): Technical Program Member

Pohl, N.

- International Microwave Symposium (IMS 2021), Atlanta (hybrid): Technical Program and Review Committee
- European Microwave Week (EuMW) 2021, London: Technical Program Committee
- IEEE BiCMOS and Compound Semiconductor Integrated Circuits and Technology Symposium (BCICTS 2021), Monterey (online): Technical Program Committee, Co-Chair for MM-Wave & THz ICs
- VDI ITG Fachausschuss 7.3 Mikrowellentechnik: Mitglied
- IEEE MTT Technical Committee MTT-24 Microwave/mm-wave Radar, Sensing, and Array Systems: Vice-Chair
- IMA (Institut für Mikrowellen- und Antennentechnik e. V.): Mitglied
- IEEE (Institute of Electrical Electronics Engineers): Senior Member

Uschkerat, U.

- EDA CapTech Radar: German Governmental Expert
- BMVI Nationale Vorbereitungsgruppe zur WRC-23 (NVG23): Mitglied
- ETSI TGUWB: Mitglied
- International Radar Symposium (IRS) 2021: Technical Program Committee

Walterscheid, I.

- IIGARSS 2021: Scientific Committee
- EUSAR 2021: Award Committee, Technical Program Committee
- IEEE (Institute of Electrical Electronics Engineers): Senior Member
- VDE-ITG: Member

Wasserzier, C.

- NATO STO Group SET-287 »Characterization of Noise Radar« : Chair
- International Radar Symposium (IRS) 2021: Technical Program Member
- IEEE Sensor Signal Processing for Defense (SSPD) TP committee member

Weinmann, F.

- VDE-ITG Fachausschuss HF 1 »Antennen«: Mitglied
- European Conference on Antennas and Propagation (EuCAP) 2021: Technical Review Committee und Session Chair
- IEEE Antennas and Propagation Standards WG P2816: Mitglied
- EurAAP Working Group »Active Array Antennas« (WGA3): Mitglied
- EMWT'21 Specialist Meeting on Electromagnetic Waves and Wind Turbines: Technical Committee

Weiß, M.

- EUSAR 2021, Leipzig/online: Technical Chair, EUSAR Executive
- IGARSS 2021, Brussels/online: Technical Program Member
- European Radar Conference (EuRAD) 2021: Technical Program Member
- International Radar Symposium (IRS) 2021: Technical Program Member
- Signal Processing Symposium (SPSympo) 2021, Lodz/online: Technical Program Member
- ICARES 2021, BALI-Indonesia, 3-4 November 2021: Technical Program Member
- KIT 2021, Vysoke Tatry on October 13-15, 2021: Technical Program Member

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left:
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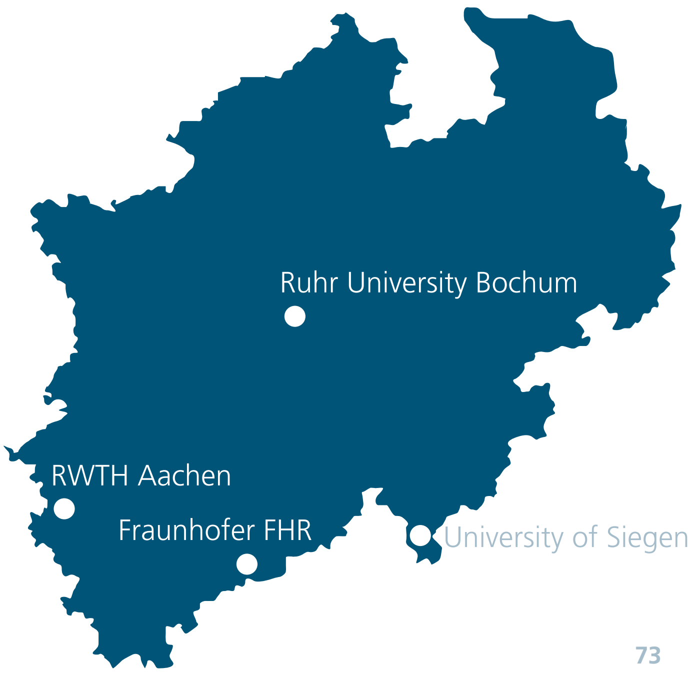
right:
Our locations in North Rhine-Westphalia



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