Fraunhofer FHR

Fraunhofer Institute for
High Frequency Physics and
Radar Techniques FHR

Annual Report 2022

Network. Exchange. Cooperation.

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Network. Exchange. Cooperation.

Preface

**Dear Friends and Partners of Fraunhofer FHR,
Dear Readers,**

dithe effects of the pandemic and global political developments have also had a strong impact on Fraunhofer FHR in 2022. Price increases, shortage of raw materials and the shortage of skilled workers also present us with unexpected challenges. Nevertheless, we can look back on many successful achievements, which we would like to present to you in this annual report. We have also been able to further strengthen aspects that will be needed even more in the future for innovative research and development: Network, exchange, cooperation.

For example, we are proud to have been involved since 2022 as coordinator of the terahertz.NRW research network in a consortium with the Ruhr University Bochum, the University of Duisburg-Essen, the University of Wuppertal and the Fraunhofer Institute for Microelectronic Circuits IMS to further develop the technological potential of THz technology and to lead the foreseeable international wave of innovation with excellent research. You can read more about this on p. 12. As part of the Research Fab Microelectronics Germany FMD, a central point of contact for all issues relating to microelectronics and nanoelectronics in Germany and Europe and a pioneer in cross-site and cross-technology collaboration, we are helping to solve current and future challenges in electronics research (report p. 26).

We reached a milestone in the area of space surveillance with radar with the cooperation agreement for the commercialization of the GESTRA system. Sensor specialist HENSOLDT has agreed to collaborate with Fraunhofer FHR with the goal of transforming the technology demonstrator into a production-ready system called Custodian. To this end, HENSOLDT has acquired the necessary licenses from the Fraunhofer-Gesellschaft and concluded a cooperation agreement (report p. 37).

We also got a lot underway internally: For example, we set the course for the future requirements of cooperation in large-scale projects by filling the two new staff unit of Process and Quality Management and Product Assurance. You can read more about this on p. 8.

Network, exchange and cooperation were also the focus of our 10th Wachtberg Forum, which we held for the first time at the Villip site last summer (report p. 14). It was a highlight of the year to finally be able to present our research work »live and on site« again after a two-year break from Corona. Once again, the great importance of personal contact was demonstrated and we are already looking forward to the Wachtberg Forum 2023 – this year for the first time a two-day event from June 21 to 22. Please save the date!

We wish you an exciting read!

Best wishes from Wachtberg

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Table of Content

Quality issues with a tailwind

Quality management and product assurance: Employees in two new staff units support the institute's staff in increasing efficiency and quality.

A lot has happened in the area of quality management and product assurance: Two new staff units were filled in 2022. Danijela Bagaric has been dedicated to process and quality management since March 2022, and Denise Potinius has been fleshing out the topic of product assurance since September 2022.

Product assurance: keeping the threads together

But what is product assurance all about? »We work together with the German Aerospace Center DLR on several major projects,« Potinius explains. »We naturally want to satisfy this central customer by meeting its requirements.« Product assurance extends beyond quality assurance, as many topics are involved that would not classically be understood as part of it. »The tasks often overlap with those of other departments. Topics such as supplier and risk management also play a role, for example. They have to be considered and coordinated with the other parties involved,« Potinius mentioned further.

»Beyond pure requirements fulfillment, we also look at what quality assurance brings to the institute and what we can take away from the individual projects for our processes. It is also particularly important to me that the processes are lived and supported by the employees,« she describes. In this sense, Potinius pulls the strings together and also fulfills a certain translator function between customer requirements and employees.

Process and quality management: focus on processes

While Potinius currently works on a project basis, Bagaric's perspective is strategic, across departments and processes. »The external need is primarily to increase customer satisfaction. The internal motivation is to increase the transparency and structure of processes through process and quality management in order to be able to work in a more goal-oriented manner, as well as to create the basis for more digitization,« Bagaric describes. She is by no means concerned with documenting everything down to the last detail; instead, the focus is on balancing the necessary specifications with the necessary freedom. In this regard, she involves the quality officers of the departments in her work - together they develop processes to full maturity. She also wants to improve work processes in a structured way and, despite the short time available, has already introduced feedback structures: All employees can identify and communicate potential for improvement in processes. In this way, processes can be continuously improved - also in the interests of customers and employees. Further steps have also already been taken. For example, Bagaric has built up a process map and made a significant contribution to its introduction using the cloud-based Microsoft SharePoint solution. This forms the foundation for solving upcoming tasks.

Successful collaboration

As different as Potinius' and Bagaric's tasks may be, they still intertwine in many ways. »The teams in project quality management have already standardized some processes. Danijela and I work together on these to make the findings usable across projects and

departments. That's what makes the task so exciting,« Potinius explains. So when there are issues or needs, the two take a consolidated approach and create the necessary processes. One example of the joint work is in risk management: This is to become viable and consistent across topics, departments and projects. Bagaric and Potinius have already drafted an initial set of evaluation criteria: Now it's time for fine-tuning and coordination with the departments that have already contributed important input.

A collegial, cooperative working style is important to Bagaric and Potinius. »We discuss the relevant issues with the departments and work together on various topics. So our work is very communication-intensive, which is a lot of fun,« Bagaric describes. To do justice to the large amount of work, the staff positions are expected to grow in the coming year. »We are still at the beginning,« Bagaric tells us. »We have already achieved quite a bit and have been able to identify where there is currently a need for further improvement. The road to optimal processes is still long. After all, the goals are designed for the long term. They should also be continuously adapted to the needs of the institute, customers and employees.«

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Special events in 2022

Bonn, March 8-10
Applied research for defense and security in Germany

Wachtberg, March 8
Triple success in the final examination for precision mechanic: Anton Schröder is best of the year in the Bonn-Rhein-Sieg Guild, winner of the Cologne Chamber of Trades and Crafts and third in the North Rhine-Westphalia German Crafts Competition.

Bonn, May 12
AFCEA Bonn e.V. Study Award for Peter Toth
Following the ICT Young Researcher Award from RWTH Aachen University, the former electrical engineering master's student receives another prize for his master's thesis written in the Cryogenic Arrays group.

Bonn, May 12-13
13th Bonn Science Night
Fraunhofer FHR presents current research projects together with the research institutions and universities of the #wissenschaftsregionbonn.

January February March April May June

London, April 2-4
European Microwave Week
Fraunhofer FHR showed a wide range of its research activities and radar applications at the joint booth with the Dutch Organization for Applied Scientific Research TNO, the VTT Technical Research Center and Fraunhofer IAF.

Wachtberg, April 12
Conference of the mayors of the Rhine-Sieg County at Fraunhofer FHR

Wachtberg-Villip, May 23
Dr. Dirk Nüßler is Fraunhofer research manager

Wesel, June 10
Final demonstration of Lupe+
With the localization of a buried person and the extraction of their respiratory parameters, the final presentation of the BMBF-funded project Lupe+ at the training ground of THW Wesel delivered promising results for the improvement of buried person detection after earthquakes, avalanches, etc.

Wachtberg-Villip, June 24
Board of Trustees meeting

Dresden, September 27
Dr. Stephan Palm receives DLR dissertation prize at the German Aerospace Congress
With his dissertation »Mapping of urban scenes by single-channel mmW FMCW SAR on circular flight and curved car trajectories« Dr. Stephan Palm won the DLR Dissertation Award 2022 of the »German Aerospace Society – Lilientahl-Oberth e.V.«


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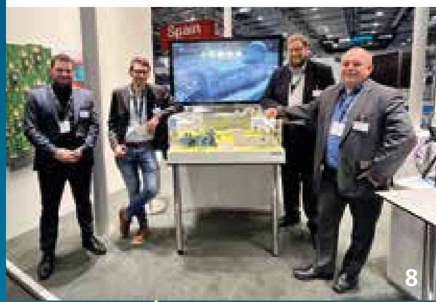
Bonn, August 18
Business Run Bonn

7

Bremen, November 15-17
Space Tech Expo
Fraunhofer FHR presented its expertise in space surveillance at a joint booth of the Fraunhofer Alliance AVIATION & SPACE. The focus was on the GESTRA networks under the motto: »State-of-the-art technology meets sensor data fusion«.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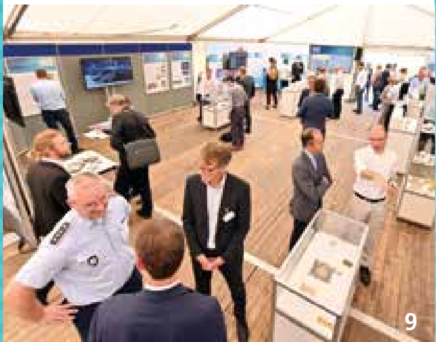
Wachtberg, October 17
NATO STO Excellence Award 2022 for Dr. Matthias Weiß
For his outstanding work in the group SET-232/SET-236 »Design and Analysis of Compressive Sensing Techniques for Radar, ESM and Electro-Optical Systems« Dr. Matthias Weiß was awarded.

Online, July 4-7
13th International Summer School on Radar/SAR.
53 participants from 12 countries completed a top-class program with 9 lectures by international experts, 6 workshops, social events and virtual institute tour.

July August September October November December

Milan, September 25-30
25. European Microwave Week

Wachtberg-Villip, June 23
10th Wachtberg Forum
Successful anniversary: There were many reasons to celebrate at this year's Wachtberg Forum: The first event after a two-year Corona hiatus, the 10th since its inception in 2009, the first time at the Villip location, and the premiere as a hybrid event with on-site and virtual participants.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Wachtberg, October 28
Large-scale exercise of the Wachtberg fire department around TIRA


10

Aachen, November 10
Bonding


11

Bochum, October 27
terahertz.NRW kick-off at the Ruhr Technology Center

Sankt Augustin, November 10
Company Day Bonn-Rhein-Sieg University of Applied Sciences

Pure networking!

Terahertz radiation offers interesting properties that can be used in numerous specialist areas. The terahertz.NRW network brings together experts from the terahertz field with those from other disciplines.

How do nutrients transport in leaves? How do plants change in their structure, growth and composition when, for example, they are under climatic stress or no longer have sufficient nutrients available? Biologists working on such questions are usually not very well versed in terahertz technology. On the other hand, terahertz experts usually have to pass on questions from the depths of biology. The terahertz.NRW network is therefore now intended to link terahertz research with other disciplines: This will enable scientists from different disciplines to benefit from terahertz technology. And, to stay with the example of biology, together they can look inside plants via terahertz beams.

terahertz.NRW: Funded with 17.7 million euros

The terahertz.NRW project was launched in August 2022, funded by the Ministry of Culture and Science of North Rhine-Westphalia in the »Networks 2021« funding program. The aim of the funding program is to sustainably strengthen and expand existing research networks of universities, universities of applied sciences and non-university research institutions, making them more visible and internationally competitive. The support is designed to run for four years from August 2022. Of the 19 networks that applied, five received funding: terahertz.NRW is the largest network to receive funding in this context, with 17.7 million euros. The three universities involved are Ruhr-Universität Bochum, University of Duisburg-Essen and Bergische Universität Wuppertal with a total of 25 institutes, as well as Fraunhofer FHR and Fraunhofer IMS with a total of six departments. The Fraunhofer FHR is in charge of the project.

In contrast to the usual research funding, terahertz.NRW focuses not only on the research itself, but also on the network. This is reflected, among other things, in the importance of funding programs, for which about 25 percent of the total amount is used. Among other things, the funding takes place in the area of gender: How do you get more women into STEM fields, especially electrical engineering, where the female quota is currently 20 percent? There are also to be scholarships.

Terahertz radiation: What's behind it?

The network's goal is to help other disciplines benefit from terahertz technology. But what actually is terahertz radiation, and what are its advantages? Terahertz radiation is a frequency range from 100 gigahertz to ten terahertz, i.e. it lies between infrared radiation and microwaves. It is true that such radiation is strongly attenuated by the atmosphere, so it does not have a long range, which is why it is not possible to see very far with it. However, terahertz radiation is one of the few frequency ranges in which large frequency bandwidths are still available, and the radiation is also physically quite interesting. For example, terahertz radiation can be used to find absorption lines of gases and solids. Radio astronomers have always been interested in this frequency range, since much of the cosmic background radiation is located here. On Earth, applications in the terahertz range are extremely interesting, where bandwidth or

top and center:
Prof. Peter Knott and Dr. Dirk Nüßler spoke in Bochum at the terahertz.NRW kick-off.

bottom:
United competence: The participants of the terahertz.NRW kick-off event.

material characterization is not the issue, but rather long range. One example is the transmission of data from a computer to a monitor, which is done today via cable. However, with increasing resolution, the cable reaches its limits, in which case terahertz waves could be used - the high attenuation due to the atmosphere is irrelevant because of the short distances, whereas the large bandwidth is quite attractive.

In which areas does terahertz radiation offer added value?

All other applications of terahertz radiation also relate to the short range: be it in medical technology, environmental monitoring, material characterization, communication or localization. As far as medicine is concerned, non-invasive terahertz sensor technologies could help classify tissues, for example during surgery, and look inside the body with endoscopes to analyze and remove cancer.

In the area of materials characterization, the focus is on high-precision terahertz imaging systems and materials and structural imaging in three dimensions. The biology department can benefit from real-time observation of the transport rates of nutrients under different environmental conditions - such as differences between day and night, and plant responses to soil amendments or stress.

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10th Wachtberg Forum: Successful anniversary

There were many reasons to celebrate at the Wachtberg Forum 2022: the first event after a two-year break from Corona, the 10th since its founding in 2009, the first time at the Villip site, and the premiere as a hybrid event with on-site and virtual participants.

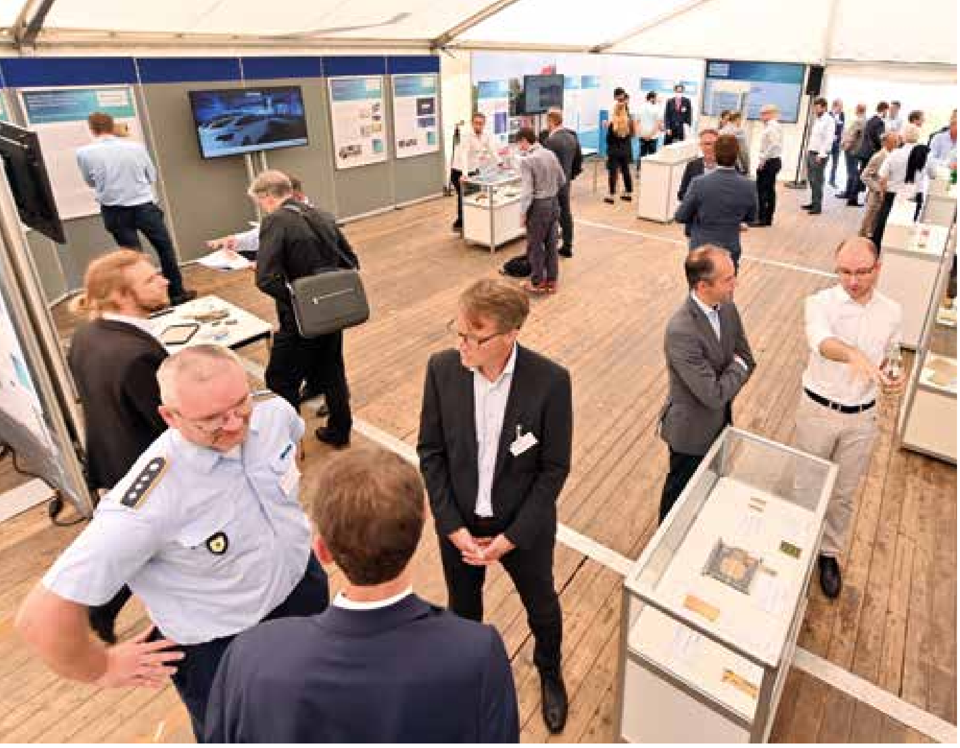
Under the motto »With radar into the future«, the exhibition with many exhibits and live demonstrations showed current projects in a practical way, complemented by 11 lectures on stage. The topics impressively illustrated the wide range of possible applications for radar: from space situational awareness to AI-supported radar systems and additive processes in the development of high-frequency components to material analysis for quality control and much more.

Whether customers, partners or clients: guests from industry, defense, science and politics took the opportunity in bright summer weather to get an up-to-date overview of the work of Fraunhofer FHR and to meet project contact persons. The new office and laboratory building Villip II could also be visited. In addition to a visit of the Wachtberg Forum on site, there was for the first time the possibility to participate online. More than 50 participants joined digitally.

The weather gods were kind to the Wachtberg Forum again this year and almost meant it too well: With sunshades, cold drinks and last but not least an ice cream van, the guests and employees braved the summer heat. The location in Villip II also passed the premiere successfully. »We are delighted with an all-round successful anniversary event. The great response from visitors shows us that the Wachtberg Forum is a fixed point in the annual calendar of our customers and partners,« concludes Prof. Peter Knott.

The 11th Wachtberg Forum will take place from June 21 to 22, 2023. Then again at the Werthhoven site around the TIRA space observation radar.

Impressions of the Wachtberg Forum in Wachtberg-Villip on June 23, 2022.

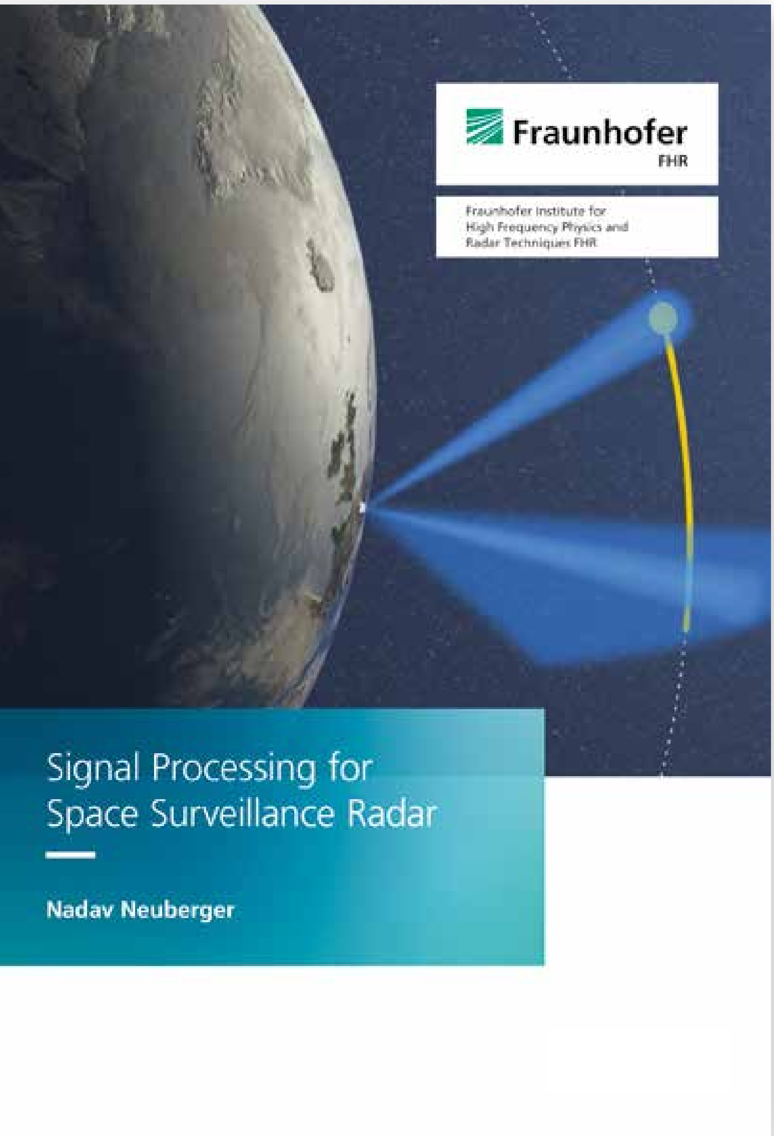




Radarsensoren bieten die Möglichkeit, unter die Oberflä
Bisher wurde der Fähigkeit von Radarsystemen, unter die Oberfläche von Bauwerken zu blicken, wenig Beachtung geschenkt.



Doctorate at Fraunhofer FHR



Dr. Nadav Neuberger

Dr. Nadav Neuberger from the Signal Processing for Surveillance Radar group in the Array based Radar Imaging Department successfully defended his dissertation entitled »Signal Processing for Space Surveillance Radar« in February 2022. Dr. Neuberger earned his bachelor's and master's degrees in electrical engineering in Israel and has worked as an electrical engineer in the private sector in large companies and small startups. In 2018, an exciting research position brought him to the Institute and he started his PhD in Electrical Engineering and Computer Science at the University of Siegen under Prof. Dr.-Ing. Joachim Ender.

With his doctoral thesis, he followed his interest in going deeper into the theory of radar signal processing. »Radar signal processing in itself has been around for decades. However, there is a great potential for new methods that are better suited for the space surveillance scenario – especially for the detection of space debris in low-Earth orbit. In my work, I focused on new signal processing methods tailored to debris detection and parameter estimation,« Dr. Neuberger says. The topic arose from his task of developing signal processing for GESTRA. Some of the new methods include a new Rx beamformer for accurate direction-of-arrival (DOA) estimation and sensitive detection. Similarly, two new FM-encoded waveforms will be introduced to solve various sidelobe challenges within range Doppler processing.

»The institute and my colleagues have supported my PhD perfectly in every way. Likewise, I am very grateful for the excellent supervision by Prof. Ender – as a leader of the worldwide radar community, he makes an invaluable contribution to students and scientific colleagues,« Dr. Neuberger summarizes.

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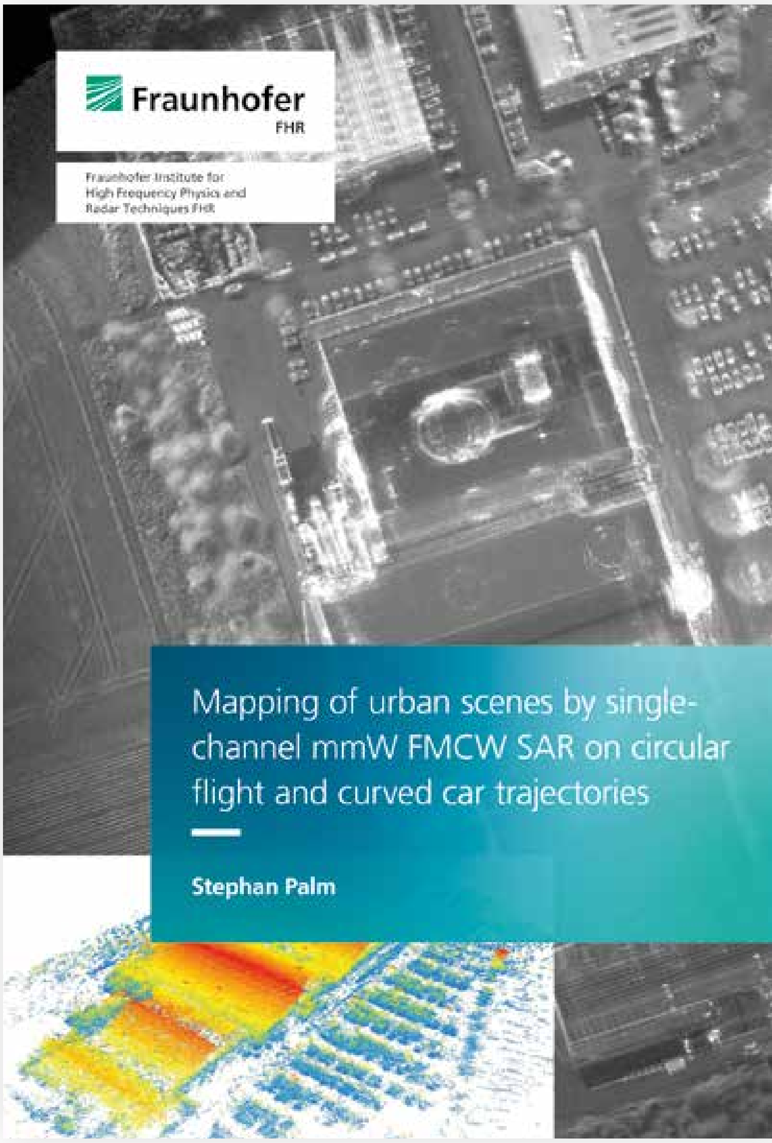
The promotion of scientific excellence is an important concern of Fraunhofer FHR. The institute therefore actively supports scientists on their way to doctoral studies. Depending on the personal research focus and interests, there are individually tailored supervision and support options.

Dr. Stephan Palm

At the end of December 2021, Dr. Stephan Palm, a member of the SAR and Algorithms @mmW group in the High Frequency Radar and Applications department, successfully defended his PhD thesis »Mapping of urban scenes by single-channel mmW FMCW SAR on circular flight and curved car trajectories« at the TU Munich. His doctoral supervisor was Prof. Dr.-Ing. Uwe Stilla.

The thesis deals with the development of an airborne circular SAR system including new data processing methods, combined with high-resolution imaging of roads and facades (radar mobile mapping) and 3D point cloud extraction. Dr. Palm published the results in three journal papers and at various conferences. »I was able to show what is possible with a single-channel SAR system using circular geometry in the W-band: azimuth resolution down to 1 cm, height resolution down to 10 cm, and detection and visualization of moving targets such as people and vehicles. The biggest challenge was to develop a system capable of acquiring experimental 360° data in the W-band in the first place. For this purpose, among other things, companies had to be found that manufacture subcomponents of the special hardware. Likewise, processing the amount of data from the 3D point cloud was very challenging, i.e., setting up the processing chain and making it efficient,« says Dr. Palm.

Dr. Palm came to Fraunhofer FHR in 2011 after completing his studies in technical computer science at RWTH, and started his doctoral studies in 2013. »I can only report good things about my doctoral conditions at the institute: I had a high degree of creative freedom for my work, as its content fit very well with our projects. Department heads and colleagues always supported me and were always on hand with advice and support. The opportunity to attend conferences and exchange ideas with other universities was also ideal. For example, at the beginning of my doctorate, I had a 10-day stay at the University of Zurich as a start to SAR processing,« says Dr. Palm looking back.



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Doctorate at Fraunhofer FHR

Dr. Simon Wagner

Dr. Simon Wagner, Group Leader Machine Learning for Radar Applications in the Department of Cognitive Radar (KR), successfully defended his doctoral thesis on »Radar Target Classification via Sparse Decomposition« at the Chair of Highest Frequency Technology and Quantum Electronics at the University of Siegen under Prof. Dr.-Ing. Peter Haring Bolívar in April 2022. Doctoral advisor and supervisor at Fraunhofer FHR was Prof. Dr.-Ing. Joachim Ender.

In 2012, Dr. Wagner visited Fraunhofer FHR as a student of electrical engineering in Trier and got to know Prof. Ender, who developed the rough direction of the research approaches together with him. Thus, Dr. Wagner wrote his master's thesis at the institute and has been working as a scientist in the KR department (until 2014 PSK) ever since. The further development of the master's topic resulted in the topic of the doctoral thesis. In it, he investigated how to detect different types of reflectors in ISAR images. In one application, a TIRA-measured aircraft was divided into the reflectors engines and point targets, where the tail created behind engines was exploited. Dr. Wagner found a physical model and applied it for the first time in a classification method that describes this phenomenon. The determination of the position and number of thrusters provides the classifier with valuable additional information for the classification of the object.

He wrote his doctoral thesis detached from his daily work and so there were always project-related breaks in the doctoral work. »On the one hand, it is a challenge to persevere over a longer period of time, but on the other hand, I had new ideas again after the breaks,« says Dr. Wagner. The institute has always supported him well in his endeavor. »The mathematician colleagues in my department helped me a lot with the proofs in my thesis. Visits to the radar conferences in London, Pisa and New York were also great – at EURAD 2016, I won the Best Paper Award with my topic,« Dr. Wagner sums up.

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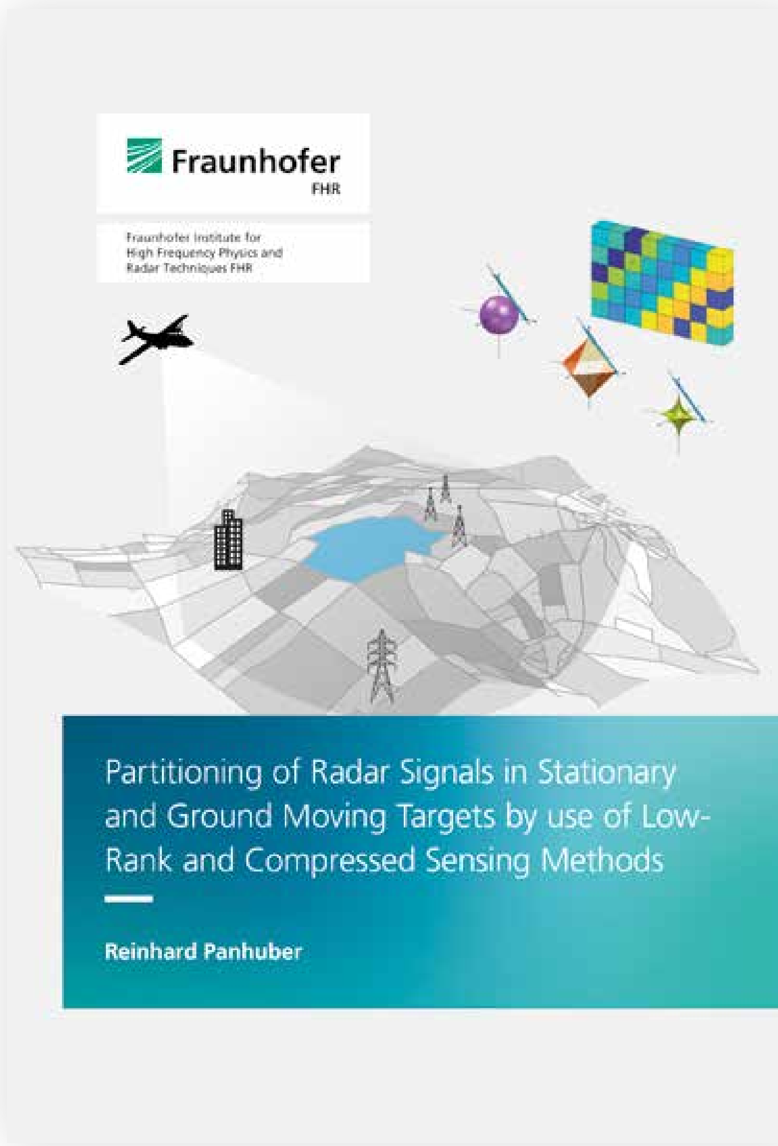
Dr. Reinhard Panhuber

In November 2022, Dr. Reinhard Panhuber successfully defended his dissertation »Partitioning of Radar Signals in Stationary and Ground Moving Targets by use of Low-Rank and Compressed Sensing Methods« at the University of Siegen. His thesis advisor was Prof. Dr.-Ing. Joachim Ender, supervisor at the institute was his group leader Dr. Ludger Prünte.

Dr. Panhuber studied information electronics at Johannes Kepler University Linz/Austria and joined Fraunhofer FHR in 2015 – in the MIMO radars and multistatics group of the Array based Radar Imaging department. In 2018, he started his PhD in the context of an industrial project. He dealt with the treatment of ground clutter in the detection of moving targets, such as cars or ships, from aircraft (Airborne – Ground Moving Target Indication/GMTI). Classically, an algorithm called Space Time Adaptive Processing (STAP) is used for GMTI. This enables the suppression of ground clutter, i.e. echoes from the earth's surface that are superimposed on the reflections of moving targets. In STAP, an adaptive filter is trained using real measurement data. STAP requires certain preconditions such as homogeneously distributed landscapes. His idea was to use modern mathematical methods like Compressed Sensing (CS), Affine Rank Minimization (ARM) and their combination Robust Principle Component Analysis (RPCA) to solve the problem of residual ground clutter. From this scenario, he developed a two-stage solution: the Auto-Clutter Focus (ACF) algorithm, a robust, patent-pending estimation technique that can estimate aircraft speed and pitch and yaw angles using the clutter signals, and the Projection Matched Filter (PMF), a powerful filter that uses the parameters estimated using the ACF algorithm.



»The PhD conditions were very good for me. I could fully concentrate on the topic. During the familiarization with the topic, Dr. Prünte in particular supported me very much and I learned extremely many new things. As the work progressed, I was naturally more on my own. You need a lot of initiative and commitment,« he concludes.

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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 2022, in its defense and civil segments, Fraunhofer FHR generated total income of €44,6 million.

Fraunhofer FHR had a total headcount of 386 at the end of 2022. Of these, 223 are permanent employees and 117 are temporary. The 46 remaining employees are students and apprentices.

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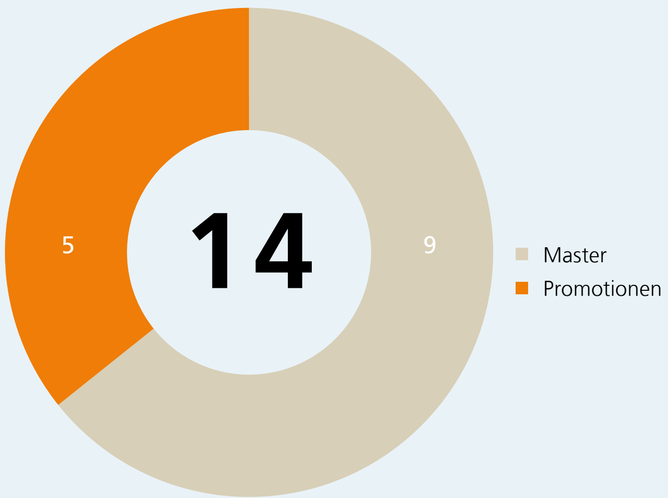
The year 2022 in numbers

Budget Development

Professorship

Degree Thesis

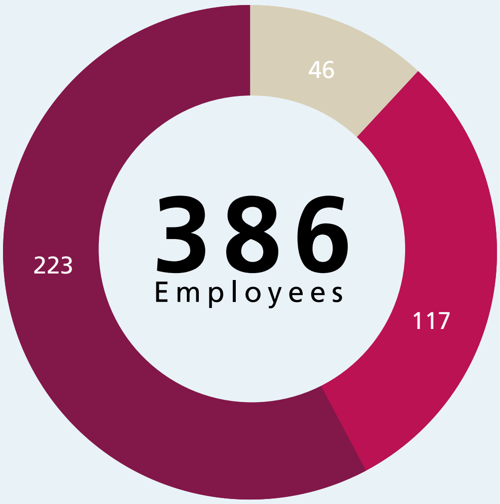


Lectures

Wintersemester 21/22: **13**

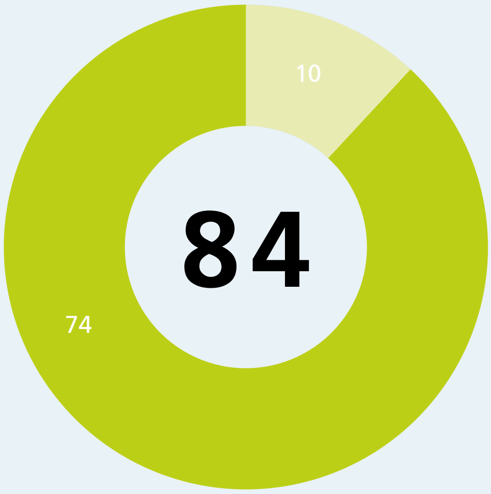
Summersemester 22: **10**

Staff



- Students Assistants, Intern, Apprentice
- Unlimited Contract
- Fixed-Term Contract

Publications



- Journals
- Conference Paper

ger. 1707
engl. 1597

1159

1438

2602

731

Media Analysis

Articles in the media: **48**

Reached contacts: **19,8 Mio**

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:

The 2022 Board of Trustees meeting took place on June 24 as a hybrid event. On site in Wachtberg-Villip were: Prof. Dr. Dirk Heberling, Prof. Dr. Peter Knott, Prof. Dr. Ilona Rolfes, Dr. Johannes Landes (Director FuE Contracts, Licenses and IPR, Fraunhofer-Zentrale), Hans Hommel, Roland Neppig (WTD81, German Armed Forces), Dr. Johannes Nowak (Research Coordinator Fraunhofer-Zentrale, Dr. Dirk Tielbürger and Wilfried Wetjen.

Chairman
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Bremen

Know-how from a single source

Together we are stronger - this also applies to the Fraunhofer Groups. In the Fraunhofer Group for Microelectronics, 16 Fraunhofer Institutes pool their expertise - Fraunhofer FHR also contributes its know-how.

The Fraunhofer Group for Microelectronics (VµE) is one of the nine research groups of the Fraunhofer-Gesellschaft and currently consists of eleven full members and five guest institutes from other Fraunhofer Groups. The Alliance spokesperson is Prof. Albert Heuberger, Institute Director of Fraunhofer IIS. Prof. Heberling is the representative of Fraunhofer FHR in the VµE.

Since April 2017, eleven Fraunhofer institutes in the Microelectronics Alliance have also been working together with the two Leibniz institutes FBH and IHP as the »Research Fab Microelectronics Germany«, or FMD for short.

Three dimensions: Internal representation, external representation and mutual support

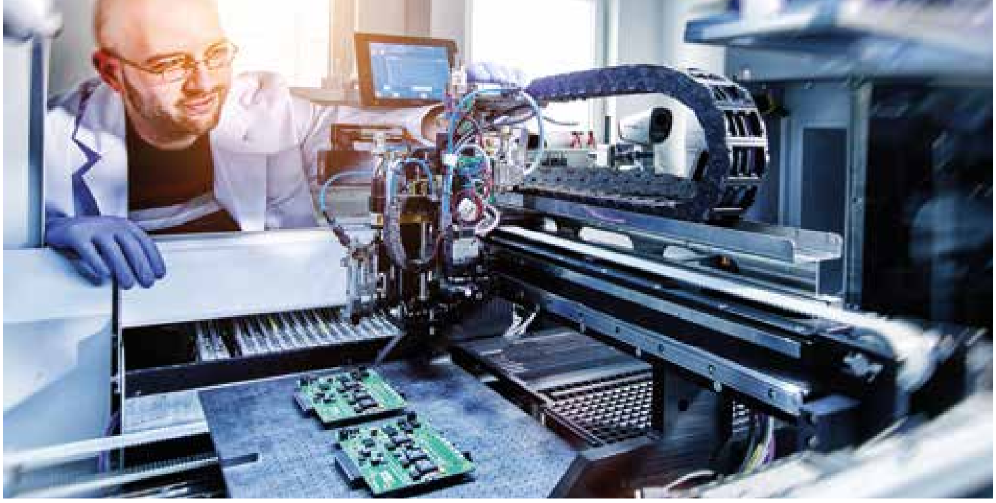
The alliance is a network within the Fraunhofer-Gesellschaft that serves three dimensions: internal political representation, external representation and mutual support. As far as the internal representation is concerned, the VµE represents the microelectronics institutes and their needs towards the Fraunhofer-Gesellschaft, e.g. clean room technology, investment or energy requirements. Furthermore, the group also acts externally vis-à-vis politics and industry. Here, the focus is primarily on the independence of supply chains, after all, microelectronics is a key technology. Thus, the VµE also has a great importance in the external area by carrying the thematic focal points of the network to the outside.

The third pillar is the mutual support of the Fraunhofer institutes in the group: After all, it bundles the competences of all Fraunhofer institutes dealing with microelectronics. Thus, Fraunhofer FHR has very close contact to the semiconductor institutes and their technology lines via the alliance - which is particularly important in the context of research funding. After all, the aim of the alliance is to offer joint research and funding projects for industry, but also to facilitate larger research programs. These are largely not in the field of radar, one of Fraunhofer FHR's core competencies, but primarily in high-frequency technology, such as communications or quantum electronics. Fraunhofer FHR would find it much more difficult to enter such programs on its own. The Microelectronics Alliance as a large partner significantly increases the clout - after all, it makes a difference whether a single institute with 250 researchers appears or an alliance comprising about 3000 employees.

Research Fab Microelectronics Germany: One-stop store for external partners

FMD is the central point of contact for all issues relating to microelectronics and nanoelectronics in Germany and Europe. As a pioneer for cross-site and cross-technology collaboration, FMD addresses current and future challenges in electronics research and provides important impetus for the development of elementary innovations for the world of tomorrow. With more than 4,500 employees, FMD is one of the largest research and development associations of its kind.

The HAGE3D enables printing with both filament and granulate. The maximum print area is 1200mm x 1200mm x 1000mm in 3-axis operation, while 5-axis operation allows complex components to be printed without support material, saving time and material.



With cross-site, cross-techno-logy and cross-competence cooperation, FMD ensures that technological sovereignty is maintained and expanded along the entire value chain.

As a one-stop store, FMD combines the scientifically excellent technologies, applications and system solutions of the cooperating institutes into a combined overall offering in the field of micro- and nanoelectronics. For example, many companies are unsure which is the right semiconductor technology for their application: the silicon technology used in computers and smartphones, the silicon-germanium technology used in the automotive sector, or the III-V semiconductors that are elementary for power amplification, among other things? This is where FMD offers external partners the necessary support and brings together the excellent individual competencies of its member institutes to create a holistic offering. With this cross-institutional bundling of know-how, the entire value chain can be served. As a one-stop store, FMD is thus the central point of contact for cooperation and industry inquiries. Research from a single source, in other words.

Forschungsfabrik Mikroelektronik Deutschland

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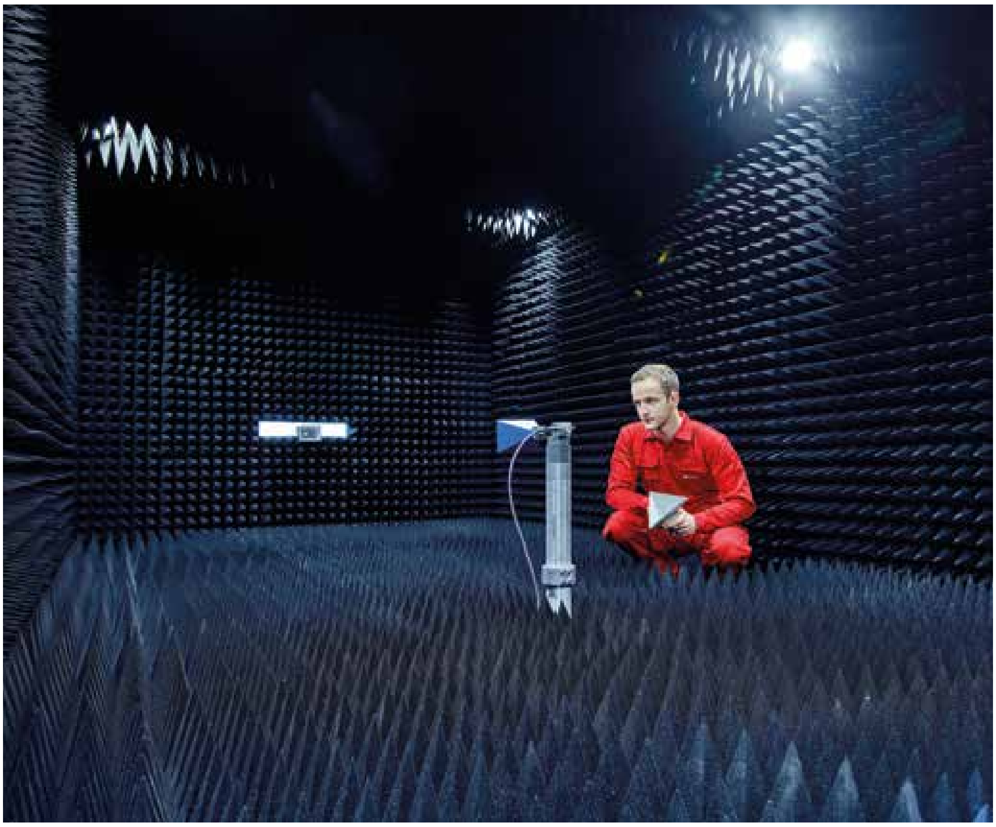

Within FMD, investments were made in an anechioc chamber in the millimeter-wave range. The interior view of the anechoic measurement chamber shows a measurement device for antenna characterization, but subsystems and complete prototypes can also be assessed.

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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.

Developed passive radar demonstrator.

Imaging radar: carried by a drone

A synthetic aperture radar (SAR) carried by a drone and adapted to its flight movements captured the first high-resolution images.

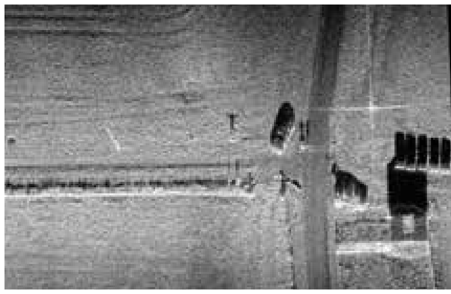
During disasters, it can be important for rescue workers to get a »quick« overview of the situation - preferably from a bird's eye view. Border guards and the military face similar issues. Drones are ideal for such reconnaissance. However, if they carry optical cameras, they have to rely on good weather: In fog, dense rain, smoke or darkness, they are hardly an asset. Radar devices, on the other hand, can see unhindered through fog and the like. The shortcoming is that high-frequency, high-performance radar units, whose resolution is close to that of optical devices, have been far too large and heavy for drones. They require larger carriers, such as ultralight aircraft.

94-gigahertz radar, nine kilograms light

Researchers at Fraunhofer FHR have now miniaturized such high-frequency SAR radars: The 94-gigahertz device developed weighs just nine kilograms, light enough for a drone. The research team had to adapt not only the hardware, but also the algorithms behind it. After all, a drone moves in a completely different way than an airplane: It flies tight, fast turns and circles, is influenced much more strongly by the wind - it wobbles and vibrates more strongly - and sometimes comes to a complete stop or even flies backward. If the miniaturized radar is to produce useful images, the flight path must be known to the millimeter. However, high-precision measurement sensors for determining the position are difficult to obtain and, at over 100,000 euros, extremely expensive. The researchers therefore tested more cost-effective MEMS sensor technology, short for Micro-Electro-Mechanical-System, which is already available for less than 20,000 euros. How is imaging changing? Which components provide sufficient output power despite high and broadband transmission frequency? The question of transmitting power could be solved in particular by components from Fraunhofer IAF in Freiburg.

Vehicle tracks in grass can be visualized

Initially, it was questionable whether such a drone-compatible system would be able to generate a focused image at all. The result is surprising: the resolution of the images, at around five centimeters, is only slightly worse than that recorded from an airplane, which comes in at up to two centimeters. At flight altitudes of 30 to 70 meters, the system was not only able to detect parked vehicles and people, but even visualize vehicle tracks in the grass. In a follow-up project, the radar's weight is to be reduced to less than seven kilograms, and it is also to process its data in real time and send it to the ground, where the images can be followed live via video stream.



top: High-resolution SAR image at 94 GHz taken by the Phoenix-94 drone SAR at a flight altitude of about 50 m AGL. The image has a resolution of about 5 cm and shows several test objects such as parked vehicles and people on an open field next to a dirt road.

bottom: Multicopter with integrated SAR sensor Phoenix-94. Weighing approximately 9 kg and operating at a carrier frequency of 94 GHz, the Phoenix-94 experimental sensor serves as a proof of concept for evaluating drone-based SAR data and imaging algorithms.

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Smaller antennas without bandwidth loss

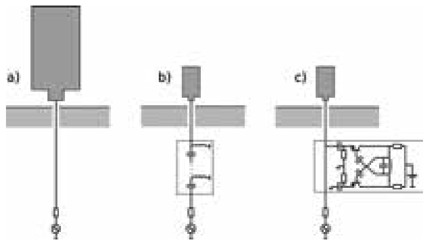
If several anteannas are mounted on platforms, this increases the platfom's visibility via radar. Upstream active networks can be used to make the antennas smaller while maintaining the same bandwidth.

It's tight on platforms like airplanes or ships: Numerous electronic components squeeze in next to a multitude of antennas. As far as the antennas are concerned, they should function as broadband as possible - in other words, cover as many frequencies as possible. However, this makes them quite large, which on the one hand causes a space problem and on the other hand ensures that the platforms can be detected more easily by enemy radar. This is because the larger the antenna surface, the more intensively radar beams are reflected from it, and the radar backscatter cross-section increases.

Trials with non-Foster networks

Can antennas be made smaller without losing bandwidth? This question was addressed by researchers at Fraunhofer FHR on behalf of MBDA Deutschland GmbH. In a first step, they investigated the maximum possible bandwidth for a fixed antenna shape. By means of an upstream circuit, a matching network, the bandwidth can be increased - up to a certain limit that cannot be exceeded. At least not if the matching network consists exclusively of passive elements without energy supply, such as capacitors and coils. If, however, active components such as transistors are integrated, this barrier falls - we then speak of non-Foster networks. With these, the antenna can, at least theoretically, have any desired bandwidth.

As far as practice is concerned, this effect can be demonstrated comparatively easily at frequencies in the two- to three-digit megahertz range. In the single-digit gigahertz range, however - the desired frequency range for the antennas - the transistors, among other things, deviate greatly from their ideal properties. The question the researchers therefore asked themselves: Is it even possible to build stable and reproducible non-Foster networks for this frequency range? The team first examined the individual passive and active components and developed circuit simulations that take into account not only the ideal behavior, but also the measured behavior of the semiconductor devices. In such circuit simulations, one assumes that the components are connected via ideal wires. In reality, however, the conduction paths develop undesirable properties as the frequency increases. The researchers therefore supplemented the circuit simulations with field simulations that take into account the strip lines between the components. What can already be said: Non-Foster networks can increase the bandwidth of antennas by single-digit percentages, even in the gigahertz range. Can this added value also be observed in practice? The researchers will investigate this in a further step.



Investigation of the achievable bandwidth of antenna shapes with reduced RCS: a) antenna with large area (high bandwidth, no matching network necessary) and large RCS b) miniaturized antenna shape (reduced RCS) with passive matching network to preserve bandwidth c) miniaturized antenna shape (reduced RCS) with non-Foster matching.

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Tunable metamaterials for antenna arrays with electronic beam steering

The scanning range of array antennas is limited, due to physical constraints. Electronically tunable metamaterials could expand it in the long term.

Chameleons have almost omnidirectional vision: This is because they can move both eyes independently. The situation is different for antenna arrays, which are electronically controlled and used, for example, in military radars or communication systems applications: Their scanning range is physically limited.

Researchers at Fraunhofer FHR are therefore using tunable metamaterials in the METALESA II project: with these, they want to improve the scaning range of curved antenna arrays, by changing the phases of the incident wavefronts coming from the antenna arrays.

Prototypes deliver promising results

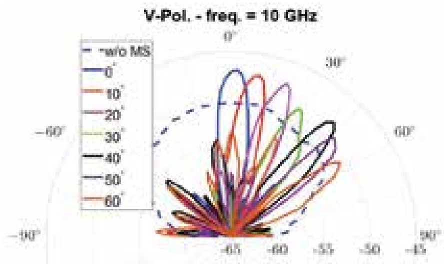
But to what extent can such tunable metamaterials change the phase of the radar radiation? Moreover, how high are the losses that occur as a result? The researchers investigated this and answered these questions by using free-space measurement test setups. To do this, they fabricated and measured two large metamaterial circuit boards - 24 centimeters by 16 centimeters. In the first experiment, they mount the tunable metamaterial PCB in front of a transmitting antenna and investigate the radiation behavior with a receiving antenna. The measured results are very promising: phase changes of up to 170° are possible for both horizontal and vertical polarization, while the losses were as low as the range of 1 to 2 dB.

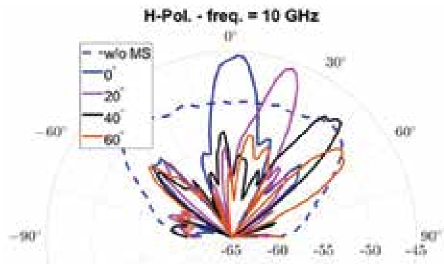
In a next step, the researchers designed and built two prototypes. The first prototype consists of a single tunable metamaterial circuit board illuminated by a single antenna element, while the second prototype consists of several tunable metamaterial circuit boards in a faceted configuration, and excited by a curved antenna array. It was successfully demonstrated that a tunable metamaterial excited by a single antenna element or a small array can perform a lens operation combined with dynamic beam scanning. A scanning range of ± 60 degrees was achieved for both the vertical and horizontal polarizations with a 3 dB increase in the gain. These results are important for small platforms like drones, among others: they are too small to carry large array antennas. In the future, the new technology will make it possible to use a lightweight, low-cost system consisting of just a single antenna instead of an array antenna and still achieve the same radiation characteristics.

The curved antenna array prototype integrated with the faceted tunable metamaterials did also perform in a convincing way: an improvement of the antenna array gain by 1 to 2 dB could be achieved for the horizontal polarization in the scanning range from 70° to 90°.

*top:
Tunable metamaterials PCBs used to improve the performance of curved antenna array.*

*bottom:
Tunable metamaterial PCB illuminated by the curved antenna array.*





*top:
Measured radiation patterns at different scanning angles in the azimuth plane with and without tunable metamaterials (vertical polarization).*

*bottom:
Measured radiation patterns at different scanning angles in the azimuth plane with and without tunable metamaterials (horizontal polarization).*

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Remote sensing and target acquisition with Starlink satellites

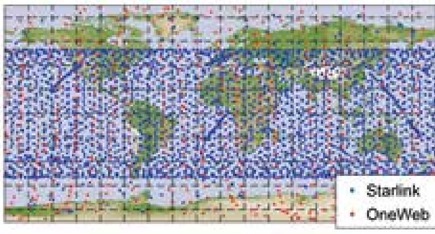
Passive radar systems offer numerous advantages. A new ground passive radar from Fraunhofer FHR uses a combination of satellite television signals and signals from Starlink satellites - enabling spectrum- and energy-efficient remote sensing.

Remote sensing - globally and permanently, without transmitting a signal? This is possible with a passive radar system that researchers at Fraunhofer FHR have developed. Unlike active radars, it does not emit radar beams that are reflected off an object back to the receiver, but uses beams that are already present. The advantage is that the system is energy-efficient and requires fewer components. A license as for active radar is also unnecessary - the system may simply be set up and thus offers great flexibility. Away from civilian applications, it offers another advantage: since the system itself does not emit radar beams, it is difficult to detect and therefore cannot be easily disturbed by interference radiation.

Radar images for remote sensing

While the precursor model SABBIA 2.0 from Fraunhofer FHR used radiation from geostationary television satellites, the researchers are expanding the possibilities even further with the current prototype. They combine the television signals with those sent to Earth by the Starlink satellites. In this way, not only can objects such as airplanes and the like be detected, but radar images can also be recorded for remote sensing. Due to the large number of Starlink satellites - at the end of 2022, there were already 3376, and the trend is rising rapidly - continuous imaging is possible. As soon as one satellite disappears on the horizon, a new one appears. This is important not only when it comes to remote sensing. The combination of both satellite signals also improves localization capabilities and classification. Finally, the object can be »illuminated« from different directions, so areas become visible that would be shadowed if there were only one transmitter. Because of the large number of Starlink satellites, the radar can also be operated in areas of the Earth that are not reached by television signals, such as Antarctica.

Currently, the prototype includes only one receiver - so the system can pick up either the signals from a geostationary television satellite or those from a Starlink satellite. In a further step, however, the researchers want to interconnect several receivers. The hardware itself has been completed, and the team is currently working on signal processing and optimizing the information they receive via the two types of satellites.



Current satellite constellations for broadband communications with global coverage.

left: Developed passive radar demonstrator.

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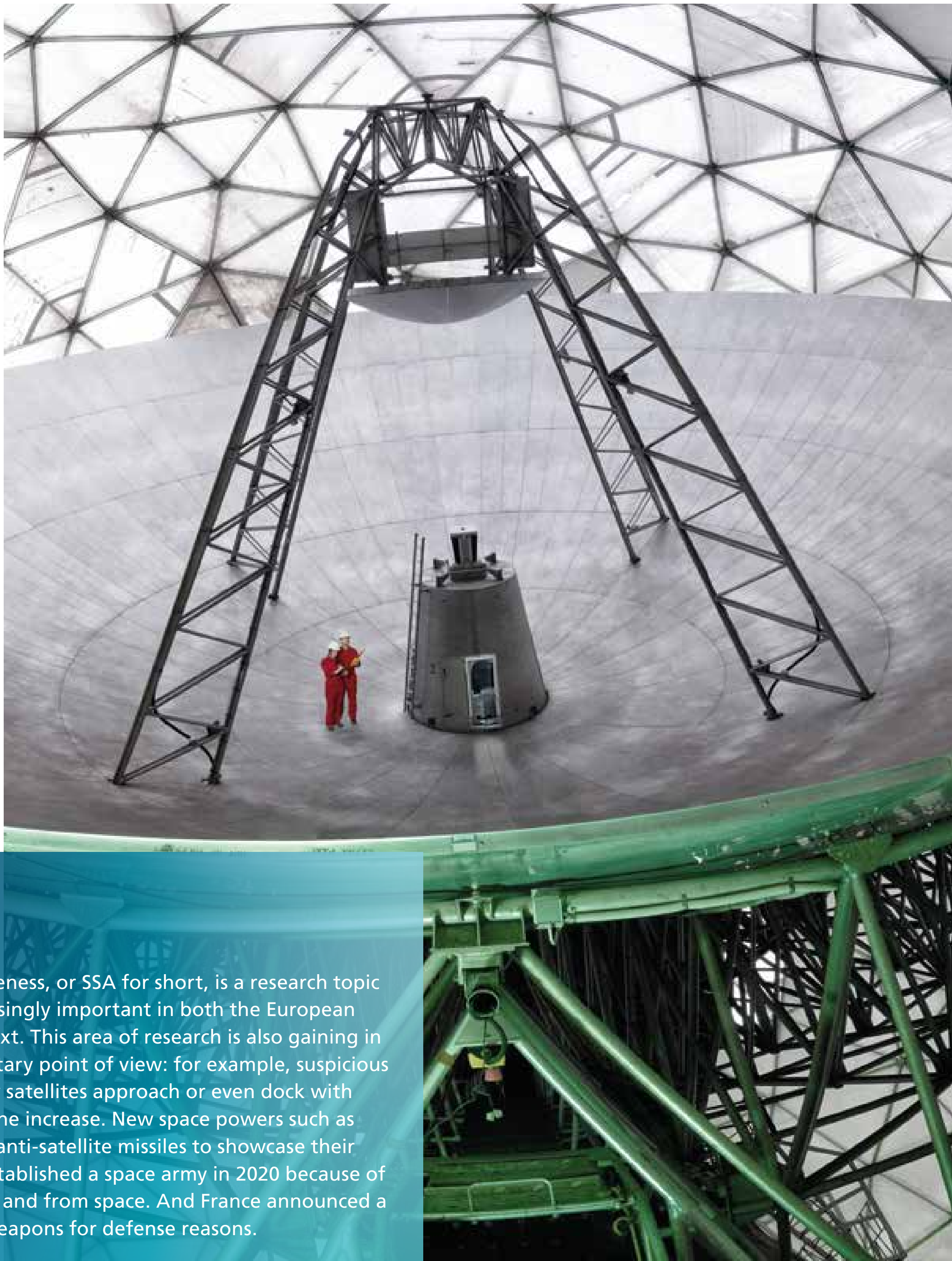


Business Unit Space

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.

The parabolic mirror of the TIRA space observation radar has a diameter of 34 m and can thus track and image the smallest space objects.

»Baptism of fire« of the space surveillance radar GESTRA

The task of the space surveillance radar GESTRA from Fraunhofer FHR: observe space debris and provide the data for its cataloging. Initial series of measurements have been promising.

At first glance, there is not much spectacular to discover: Two containers, 18 meters long, four meters wide. But they are quite something: they contain 256 transmitter modules and 256 receiver modules, which work together as a phased array antenna to detect space debris at an altitude of 300 to 3000 kilometers at a frequency of 1.3 GHz. The radar, called GESTRA – short for »German Experimental Space Surveillance and Tracking Radar« – was developed by Fraunhofer FHR on behalf of the German Space Agency at DLR for the Space Situational Awareness Center of the German Armed Forces, which will operate it in future at the Koblenz Schmidtenhöhe site. The purpose of the measurements is to catalog the scrap parts that can become projectiles with destructive force for satellites and the like.

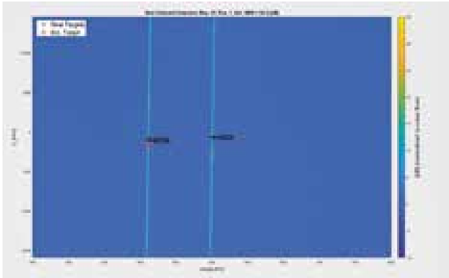
First measurements run successfully

In initial test runs, GESTRA has already shown what it can do: The radar detected calibration spheres – round spheres that make their circles in orbit – as well as decommissioned satellites, rocket end stages and other space debris. By comparing Doppler velocity and range, all of these objects were verified, and the results were within the mathematically expected range. In addition to the specified objects, GESTRA also made some »accidental finds«: objects that floated through the observed space region and could be identified using the space attitude center. Further measurements are now pending, which will include even more system features of the GESTRA radar.

In addition to the actual GESTRA development, Fraunhofer FHR researchers have been working since 2020 in the GESTRA EUSST project to build another receiver for the space surveillance radar, and the construction of an additional GESTRA-compatible transmitter unit is on the agenda in the GESTRA TX2 project. In the GESTRA networking project, in turn, the second receiver is to be networked with GESTRA: In this way, the size of the detectable objects as well as the prediction of their trajectory should improve by factors.

Outlook for the experimental-operational phase

GESTRA has been installed at the Koblenz site and is currently being tested together with the German Space Location Center. In order for the experimental system to enter its »operational phase,« Fraunhofer FHR researchers are planning corresponding acceptance tests for the further course of 2023.



top:
The transmitting and receiving unit of the GESTRA space surveillance radar in Koblenz.

bottom:
Simultaneous detection of two targets with the GESTRA space surveillance radar. The measured distance and target speed are shown

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My house, my car, my space surveillance radar?

The GESTRA space surveillance radar can be used to observe satellites, but also space debris. So who is surprised that numerous countries are expressing interest in the system? Hensoldt Sensors GmbH, as a partner of Fraunhofer FHR, is therefore now to push ahead with commercialization.

Around seven million particles float through space – from disused satellites and jettisoned protective shells to screws and fragments. And there are more every day. This is because small private companies are increasingly sending satellites into orbit, and interest in space reconnaissance is growing not only in the area of research, but also in operations. Also, more and more nations want to expand their competence in the area of space attitude, i.e. to better and more accurately track the orbit of their own satellites in order to better protect them from collisions.

GESTRA makes it possible

This is possible with the semi-mobile space surveillance radar GESTRA, which researchers at Fraunhofer FHR have developed for the Space Situational Awareness Center on behalf of the German Space Agency at DLR. It is therefore not surprising that Fraunhofer FHR is receiving an increasing number of inquiries in the direction of commercializing GESTRA, especially from states. And indeed, the project was conceived from the outset in such a way that, in addition to the experimental system, a partner would be brought on board to bring the system to market as a product. Then, well-heeled private individuals could also set up their own space observation radar in their backyard, for example, to keep an eye on their mega constellations of small satellites. However, the first customers are likely to be mainly governmental. It is also conceivable that several GESTRAs could be connected together, thus expanding the search area covered.

On the road to commercialization

Fraunhofer FHR researchers have now raised the space surveillance radar to a Technology Readiness Level of six. This data will now be handed over to Hensoldt Sensors GmbH as a partner for commercialization, and the transfer of know-how will be initiated. The commercialized version of GESTRA will thus incorporate a great deal of »lessons learned,« and thus a great deal of experiential knowledge that the Fraunhofer researchers have built up during the development of GESTRA – for example, in the area of integration into the container as well as system design. Knowledge from which the system benefits. Hensoldt will push the technology maturity level even higher and develop a commercial solution from the experimental GESTRA system.

top:
The GESTRA space surveillance radar in Koblenz is attracting interest from numerous countries.

bottom:
The antenna on the positioning unit of the receiver.

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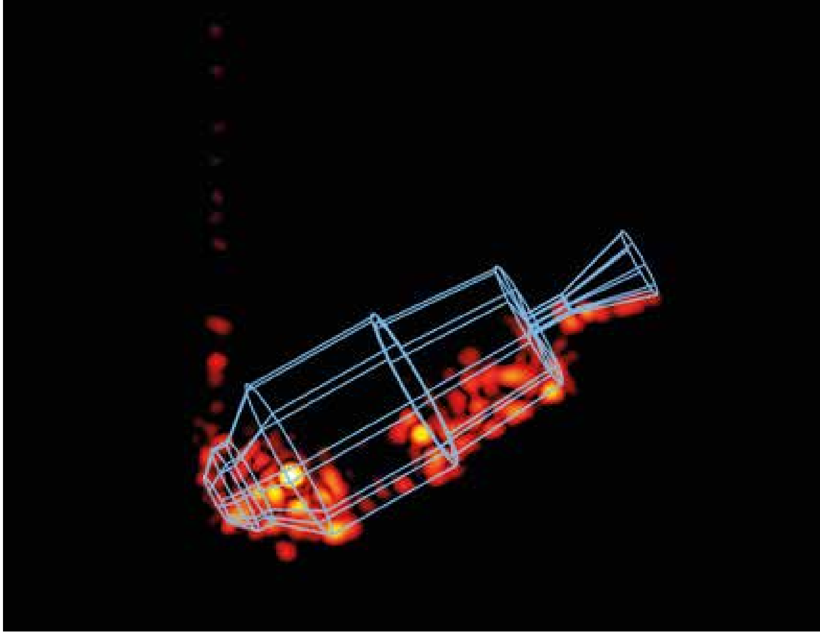
Garbage collection for orbit



The amount of space debris is steadily increasing. The Japan Aerospace Exploration Agency JAXA therefore wants to actively reduce space debris and remove some of its rocket upper stages from orbit. Fraunhofer FHR assisted in the selection of potential objects with the tracking and imaging radar TIRA.

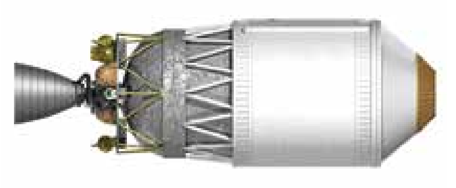
Rocket upper stages that are buzzing through the orbit without a master have a great hazard potential: After all, they can explode, either due to contained residual propellant or due to batteries. Now you might think that an explosion in orbit is no big deal – after all, there's no one there to be bothered by it. Far from it: an explosion turns a large piece of debris into tens of thousands of small pieces of debris. Debris that can become dangerous projectiles and, in the worst case, destroy satellites and the like in a collision.

Removing rocket upper stages from orbit

The Japan Aerospace Exploration Agency JAXA therefore wants to remove its rocket upper stages from orbit. That the rendezvous maneuvers required for this are feasible is to be demonstrated by the ADRAS-J demonstration mission within the CRD2 project, which is to be carried out by Astroscale by 2024. A pre-selection of potential candidates has already been made by JAXA. Still pending was a decision on exactly which upper stage to target for the mission. Simulations by the Japanese agency also showed that rocket upper stages that are in the sphere of influence of the Earth's gravitational field for a longer period of time align themselves with their longitudinal axis along this field, i.e. they always point with the »nose tip« toward the Earth's surface.

Imaging radar TIRA confirmed the simulation results of JAXA

Can Fraunhofer FHR confirm or refute these simulation results – and thus help identify a suitable candidate for »garbage collection«? JAXA employees approached the institute with this question. In a feasibility study at the end of 2021, the Fraunhofer team imaged a selected upper stage with TIRA and determined its rotation based on the image analyses. How fast does the upper stage rotate? Around which axis? And how is this axis aligned in space? The simulation results were confirmed: The nose tip of the upper stage pointed toward Earth. So did almost all the other rocket upper stages analyzed in a follow-up study in spring 2022. Only one was out of the ordinary. This one showed a slow tumbling motion at 0.1 degrees per second. The researchers, as well as JAXA, suspected that this upper stage was still in a transition phase. This is because after an upper stage has released its payload and changed course slightly, it initially flies uncontrolled through space, spinning at will. Only in the long run do various forces cause the rocket upper stage



top:
Radar image of an upper stage with simplified model superimposed.

bottom:
Generic image of an H-2A rocket upper stage. A similar upper stage is to be removed from Earth orbit as part of an Active Debris Removal (ADR) mission.

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to align itself along the Earth's gravitational field. While the object is »captured« by the Earth's gravitational field, the observed tumbling motion occurs. According to JAXA, there is much to suggest that the rocket upper stage was in this process – because the axis of rotation, which the Fraunhofer FHR researchers determined, also changed over time. The researchers found this out because they carried out six measurements per upper stage, each at intervals of about one week.

Rotational symmetry of the objects posed challenges

The investigations with the TIRA imaging radar did present challenges. One of them was the rotational symmetry of the upper stages – which is problematic for the methods used, especially the rotational axis determination. This is because individual object points have to be found again and again over the course of time on the basis of a series of images and these points have to be clearly assigned, which is very difficult in the case of a round geometry such as a cylinder. With various methods and the support of JAXA, which provided detailed information on each upper stage, the team was able to overcome this challenge. In short, the investigations with the TIRA imaging radar are helping JAXA to select specific candidates where garbage removal is likely to be successful.

Tracking and Imaging Radar (TIRA)

- Experimental radar system
- Type: 34m parabolic antenna in Cassegrain configuration
- Moving mass: 240 t
- Mechanical positioning accuracy: 0.6" (0.000172°)
- Weather protection: 47.5 m radome
- Currently 2 integrated radars

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 predictions of critical approaches.
- Temporal and spatial predictions of re-entries.
- Damage and fragmentation analysis of satellite/rocket upper stages.
- Object identification and classification
- Observation and (statistical) analysis of the space debris environment.

High-resolution imaging radar for space observation

Satellites and their attachments are becoming increasingly smaller: The view into space must therefore be improved in order to be able to see more details. A new, high-resolution, polarimetric imaging radar for the TIRA space observation radar should make this possible.

For what reason is the satellite no longer working – was it hit by space debris? Such questions can be answered with the TIRA imaging radar of Fraunhofer FHR: Via target tracking radar the trajectories of the satellites are tracked, the imaging radar collects additional data from which radar images are calculated. In the past, for example, Fraunhofer FHR was able to detect that the foil-like solar panel of the Japanese research satellite ADEOS-1 had torn off and wrapped itself around the holding mast. But technology continues to evolve – satellites and their attachments are getting smaller. TIRA imaging radar is therefore increasingly reaching its limits in terms of resolution.

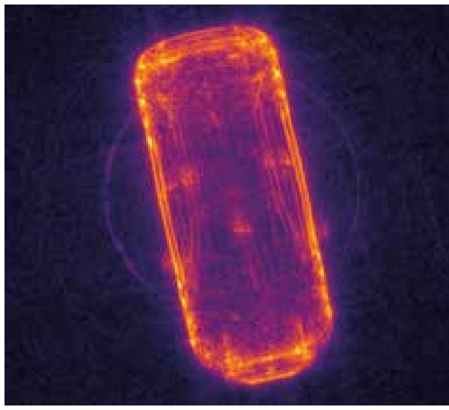
High-resolution space imaging radar

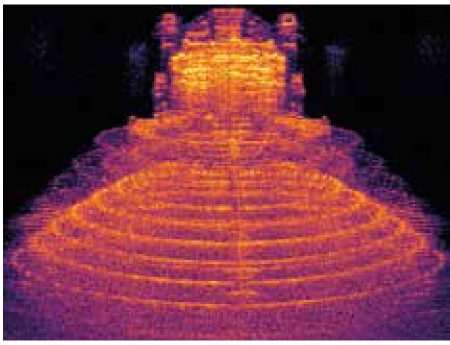
The TIRA-HD project aims to close this gap. The goal is to develop a high-resolution imaging radar that also uses the polarization of radar waves. The antenna emits differently polarized radar waves, which are reflected by the space object and received again. In this way, structures such as complex attachments can be detected and analyzed much better. While certain structures are only faintly visible in one polarization direction, they appear clearly in the other. In addition, different parts of the object that are imaged in the same image pixel can be separated from each other, which has not been possible until now. This gives TIRA completely new capabilities.

Recording extreme amounts of data

One challenge lies in the large bandwidth required for the high resolution. After all, the data must be recorded in real time – and for the different polarization directions over an observation period of about ten minutes. This adds up to several gigabytes per second. The recording unit also has to be integrated into TIRA's very limited, and in addition mobile, space and protected from overheating. The project team investigated various cooling concepts via simulation and tested them in initial iterations. It also investigated low-vibration integration options to protect the sensitive electronics during radar movements.

The recording unit has already been successfully tested at an intermediate radar frequency. For this purpose, the project team imaged, among other things, a vehicle on a rotating platform as well as the moving TIRA itself. The first radar images already look very impressive, especially considering that this is only an intermediate step towards the final radar system.





top:
First tests of the new recording unit: pictured was the moving TIRA antenna.

center:
Radar image of a spinning car recorded at an intermediate radar frequency.

bottom:
Radar image of the moving TIRA antenna recorded with the new recording unit.

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The search for the needle in the haystack

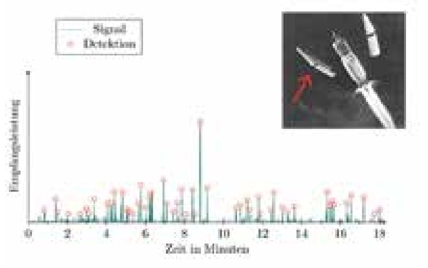
What happened when a cylinder half fragmented in orbit – was the object completely destroyed? An unusual task that the TIRA target tracking and imaging radar was able to master well.

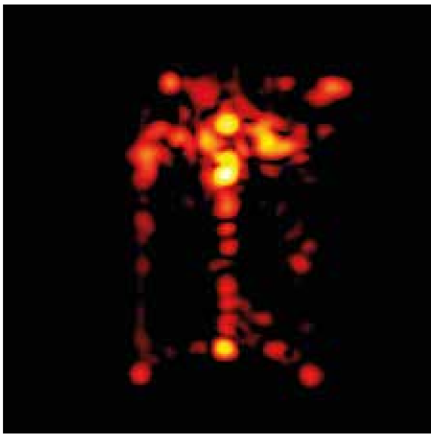
Man has left his mark on orbit: The extent of space debris is steadily increasing. Explosions of rocket upper stages, satellite launches and uncontrolled collisions of space debris further increase the number of particles whirling around. This was also the case on July 3, 2022: At shortly before six o'clock CET, the cylinder half of a shell that protects the payload from external influences during rocket launch and that is jettisoned before the satellite is released – the H-2A Payload Fairing (43674) – fragmented. Following its fragmentation, numerous questions arose: are there other pieces of debris drifting through orbit around the original object? Is there anything left of the original object, or has it been completely destroyed?

Using two different radar settings to reach the target

The German Armed Forces Space Command with its departmental Space Situation Center commissioned Fraunhofer FHR to answer these questions, using TIRA. This was a rather unusual task for TIRA and the supervising team because the system is not designed to search large parts of the sky. The outcome was uncertain. To counter it, two different settings of the radar were used. First was »staring mode«: in which the antenna is pointed at a specific part of the sky and moved only to compensate for the Earth's rotation. Earlier data provided clues as to which section to target and when debris would need to pass this observed section. To be sure not to miss the passing of the pieces, the staff started the observation with the target-tracking radar several minutes before the expected time and did not end it until another 18 minutes later. In total, they received 50 detections – a particularly strong echo occurred four minutes after the expected contact.

In order to classify this strong detection more precisely, the employees took up »tracking« in a second measurement with TIRA: Instead of looking at a constant section of the sky as before, they tracked the object and also imaged it with the target imaging radar. But how to find the object again? Since the echo occurred four minutes after the expected contact, the team calculated: the object delays by 25 seconds per day. In this way, the researchers extrapolated its reappearance and were able to find it again. The result: the object rotates very fast, at about 20 degrees per second. It also had a similar geometry to the cylinder half of the payload fairing. The researchers were able to successfully identify the object in the debris cloud – in other words, find the needle in the haystack.





top:
ISAR radar image of the second measurement: the object was several meters in size, and the round shape of a half-cylinder is clearly visible.

bottom:
Time course of the first measurement, the detections are marked: The highest peak is seen four minutes after the expected contact. Top right: A rocket upper stage ejects the protective covers - the payload fairing.

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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.

The airport – A future hotspot of 3D mobility.

Locating buried victims quickly and precisely via radar

When people are buried by debris, every second counts. For the first time, the LUPE+ radar system can detect the breathing movements of survivors and pinpoint their exact position.

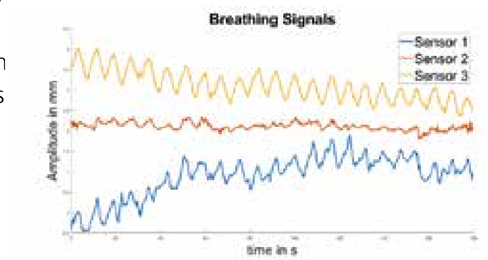
When rescue services are faced with the rubble of a house or even several buildings that have collapsed due to earthquakes, gas explosions or the ground being washed away by heavy rain, it is difficult to guess where buried people have survived and are waiting to be rescued. But fast and, above all, targeted help is needed. In the joint project LUPE+, Fraunhofer FHR has therefore developed a sensor network together with the German Federal Agency for Technical Relief and indurad GmbH: With this, signs of life of buried persons can be detected and the persons localized. The special feature: Unlike previous systems, which are complex to set up, require long measurement times - and where it is not possible to localize the buried person - the novel system can be set up in a very short time, and the measurements themselves take less than a minute.

High transmission power required

The sensor network is based on several MIMO radar sensors that operate in the frequency range from 1.1 GHz to 1.4 GHz and are connected to form a coherent - i.e. a frequency- and phase-equal - network. MIMO stands for »multiple input, multiple output« and means nothing more than that multiple transmitting and receiving antennas are used. indurad GmbH took care of the wireless coherent synchronization of the individual modules. On the one hand, the researchers from Fraunhofer FHR developed the hardware: for example, an antenna that uses both polarization directions and thus also detects signals whose polarization has been rotated due to debris. The tricky part was to provide sufficien transmitting power, since the reflected signals should still be detectable despite high losses due to the debris. The researchers achieved this by using an output power of 28 decibels milliwatts - which is above the permissible limits, but not a problem in the event of a disaster. Fraunhofer FHR was also responsible for signal processing. Here, the focus was on new approaches to detecting the minimal movements generated by breathing in the chest, as well as localizing the injured.

First test measurements successful

At the THW test site, the sensors have already been allowed to show what they can do: A »buried« person was lying in a concrete bunker - three wirelessly synchronized sensors placed around the bunker were able to measure the respiration rate and localize the person. A result that not only Fraunhofer FHR, but also the employees of the rescue organization considered very promising. In further steps, the researchers want to further optimize the evaluation by AI-supported methods and further develop the system to an operational system.



top:
LUPE+ sensor with additively manufactured housing.

center:
Measured respiration curves of the three synchronized radar sensors.

bottom:
Measurement setup bunker scenario on THW test site.

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Designing Vertiports Safely

Transporting people via air cab? It is already set to become reality at the 2024 Olympic Games in Paris. Fraunhofer FHR is developing novel concepts to monitor future 3D mobility intelligently and resiliently.

Multicopters are by no means just a gimmick: They are already being used by fire departments and disaster control. In the future, they will take on even more diverse tasks, for example in logistics and parcel transport. And in the form of »electrical vertical takeoff and landing« systems, or eVTOL for short, they will even be able to transport people. What sounds like something out of a science fiction movie should already become reality at the 2024 Olympic Games in Paris. Various airlines are planning to equip the Games with appropriate eVTOLs to transport people from the airport to the Games. The systems are still controlled by a human pilot, and one passenger is seated in each air cab. It is hoped that these drone systems could increase social acceptance to such an extent that autonomous flying vehicles will be possible in five to ten years. After all, if urbanization continues to advance, it is inevitable that transportation systems will be extended to the third dimension.

Sensor network monitors Vertiport with high precision

The take-off and landing platforms are particularly critical in the field of 3D mobility: After all, there is a lot of »crowding« there. In the interdisciplinary competence group »Civil Drone Systems«, researchers at Fraunhofer FHR are therefore developing - across departments in order to bundle competencies - a sensor network including radar sensor that monitors air traffic at the Vertiport with high precision. In contrast to established monitoring systems based on mobile communications, the system can also detect eVTOLs that do not have a corresponding communication device on board, as well as construction cranes, flocks of birds or trees blocking the entry and exit aisles. Beyond detection, the system should also be able to classify obstacles, i.e. distinguish between drone, bird and tree.

Network of numerous small sensors

To be able to implement mobile drone ports, such as those that will be needed for the Olympics, and not provide a central weak point, the researchers are relying on a network of numerous decentralized active and passive sensors that collectively scan the entire area. The size of the scanned area can also be easily adjusted. Signal processing also does not start at a central point, but is decentralized via edge computing. The long term-objective comprises any number of sensors that are automatically networked throughout the landing zone. If the sensors are aligned in such a way that they cover the airfield redundantly, shadowing and failures are also covered - the system becomes robust and resilient. It´s not only interesting for vertiports; in the future, it could also monitor corridors along which transport drones move through cities.

There is a lot of traffic at take-off and landing platforms for multicopters and air cabs. In the future, a network of radar sensors could monitor air traffic with high precision.

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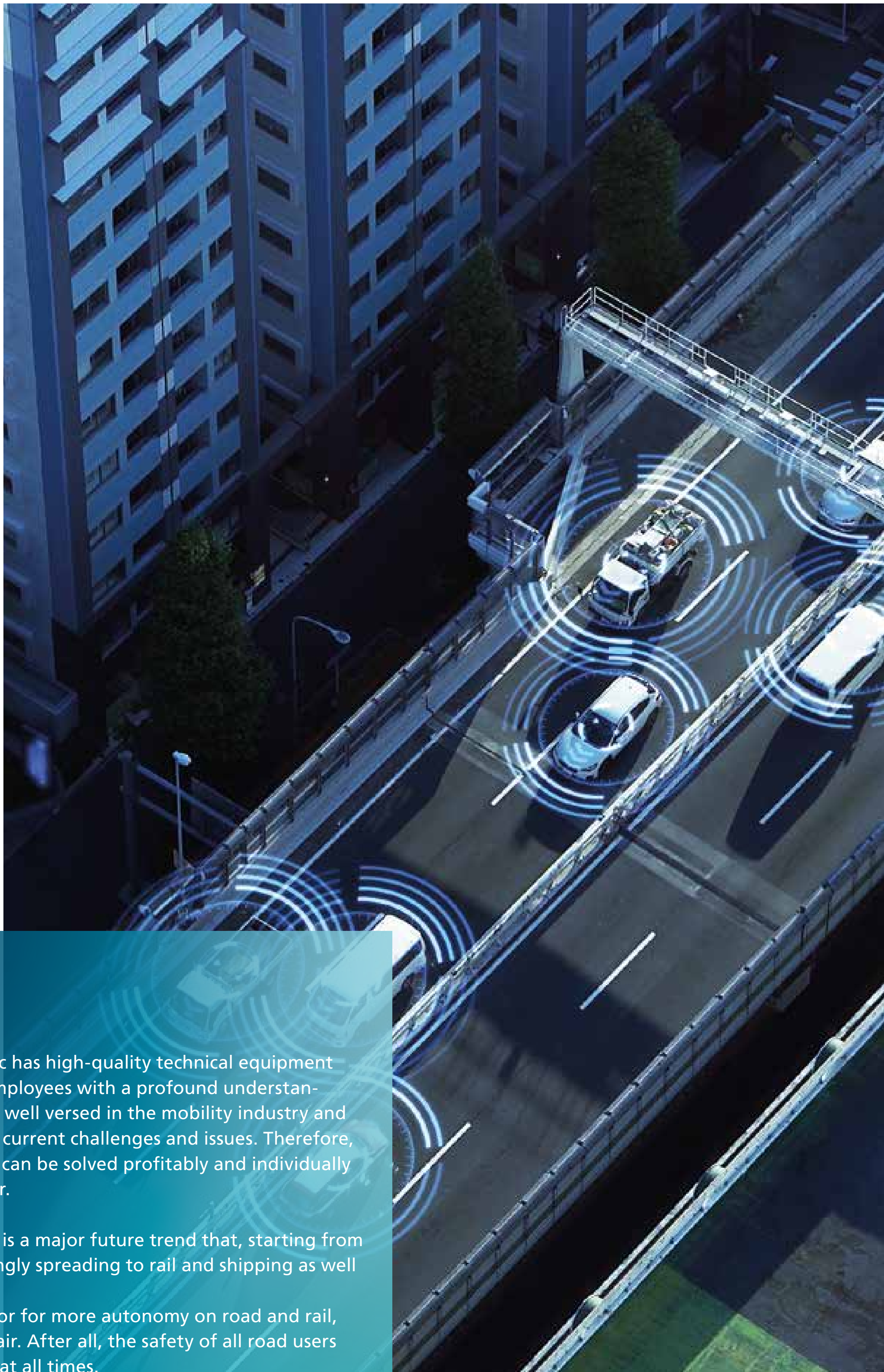


Business Unit Traffic

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.

Radar sensors are important components of driver assistance systems.

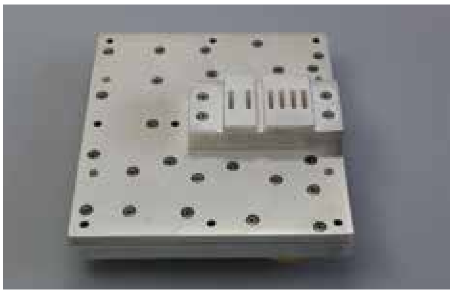
Metal-coated radar antenna from the 3D printer

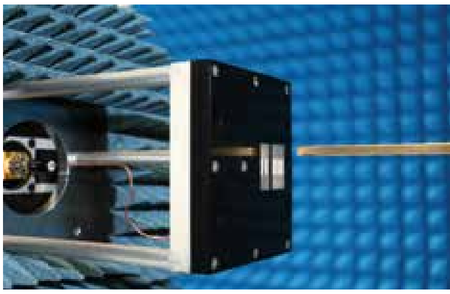
Motorized vehicles can use radar systems to detect what is happening all around them. Now state-of-the-art antenna prototypes for these systems can be produced inexpensively: via 3D printing and metal coating.

While people have eyes and ears to keep an eye on their surroundings while driving and reliably detect pedestrians, cyclists and the like, autonomous vehicles and driver assistance systems rely on sensors. For example, radar sensors, which are already installed in many cars. At least four antennas are usually required for this purpose, one transmitting and three receiving antennas. The transmitting antenna sends radar beams into its surroundings, which are reflected by various objects such as pedestrians, cyclists, cars or lampposts and deflected back to the receiving antennas. With just one receiving antenna, it is possible to calculate the distance and speed of the object. With the second, a rough angular range is obtained in which the object is located - for example, at an angle of about 30 degrees to the sensor. And with the third antenna, this angular range can be narrowed down even further. In general, the more receiving antennas, the higher the resolution and the more objects can be detected simultaneously. However, with printed microstrip antennas, losses increase when multiple antennas are used, and their bandwidth is also severely limited. Waveguide antennas are different: They are perfectly suited for multi-antenna use. However, there is another problem here. This is because waveguide antennas are usually made entirely of metal, and in many cases they are manufactured from a solid metal block - a complicated, lengthy and expensive undertaking.

Plastic printing instead of metal processing

Researchers at Fraunhofer FHR have now investigated a much more cost-effective alternative. Instead of milling the antenna from a metal block, the researchers print it from plastic using a 3D printer and then coat it with metal. To coat the internal cavities, they resort to a trick: Instead of producing the antenna in one go, they divide it into two halves - each of which also contains only half of the waveguide. These halves are coated with metal and then joined together to form a whole. The researchers compared the antenna produced in this way, printed according to Fraunhofer specifications and coated by cooperation partner Biconex GmbH, with metal antennas of identical construction. The results are impressive. The 3D-printed and coated antennas work slightly differently, but similarly well as the metal antennas - and in the entire frequency range from 67 to 81 gigahertz. So they work in both the long-range and short-range. Now, 3D printing offers great flexibility, but it's not particularly suitable for mass production. But the researchers have a solution here, too: the two halves of the antenna can be produced just as well via the mass production process of injection molding.





top:
Metal-coated 3D-printed antenna.

r:
Metal-coated 3D-printed antenna with RF absorber cover to reduce standing waves.

bottom:
Characterization of metal-coated 3D-printed antenna with Fraunhofer FHR near-field measurement system.

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Collision-free despite crowded airspace

top: Different drone systems can be identified and distinguished from each other via the system.

center: The radar system that will monitor the airspace is located underneath a helicopter.

bottom: The radar system created by HENSOLDT Sensors GmbH.

The airspace is filling up: drones are to support parcel couriers, air cabs are to relieve the roads. To prevent collisions, suitable airspace monitoring systems are needed. One is being developed in the »MIMO-Air Project«, in which Fraunhofer FHR is also participating.

There is always a lot of traffic on the roads – cities and communities are prepared for this. In the future, however, some of the traffic is likely to shift to the airspace: drones will deliver packages, air cabs will transport human passengers. While on the ground, fixed road layouts, right-of-way regulations and traffic lights prevent collisions, this is more difficult to implement in the air.

MIMO radar tracks and identifies drones and co.

A team of researchers from numerous partners – including the German Aerospace Center DLR, HENSOLDT Sensors GmbH and Fraunhofer FHR – is investigating what aerial surveillance could look like in the »MIMO-Air Project«. The goal is to develop a MIMO radar for flying platforms that can be used to avoid obstacles and collisions. For the time being, the system will be mounted under a helicopter for evaluation. The data collected by the radar device is sent via 4G data link to the ground station – where the platform operator can not only keep an eye on the flight paths via radar, but also distinguish between the different types of drones. For this purpose, the data is intuitively processed in the form of a virtual reality application.

Tracking, cognitive data processing and classification

The Fraunhofer FHR researchers from the Cognitive Radar department are concerned with three things: first of all, tracking, i.e. they use the radar data to determine the flight paths of the drones. The focus is on the second area, cognitive data processing. This is used to optimally adjust the parameters of the MIMO radar during flight and to reduce the error rate in tracking the flying objects as much as possible – using software developed for this purpose. The third part of Fraunhofer FHR's work is classification: the team uses micro-Doppler to analyze what type of drone it is.

The subsystems developed by the various project partners – HENSOLDT Sensors GmbH is creating the radar system, DFS Deutsche Flugsicherung GmbH is supporting the project with its expertise, DLR-SE is responsible for developing the ground station, DLR-FL is taking care of the 4G-DATALINK, the flight routes of drones and airport logistics, Humatects is preparing the virtual reality application – are first brought together by simulation.

The entire system will then be tested in close cooperation with DLR's Institute of Flight Guidance. Initially, ground tests are planned for October 2023 at the national testing center for unmanned aerial systems in Cochstedt. In April 2024, the system will be flight-tested in a final step, also in Cochstedt. DLR's Bo 105 helicopter will be used for this purpose.

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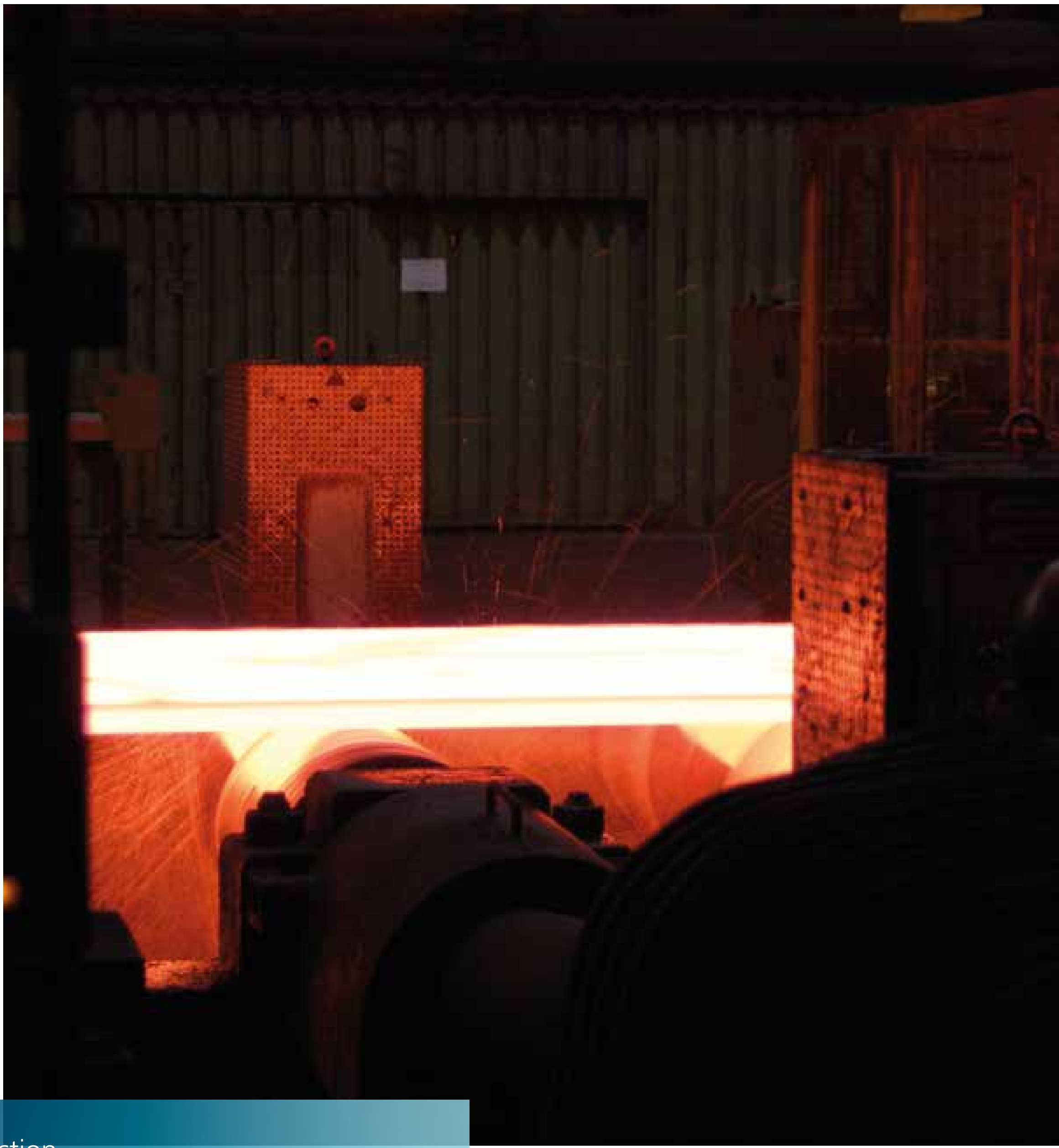

Business Unit Production

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.

Radar width measurement on the roughing stand of Salzgitter Flachstahl GmbH.

Detecting defects in glass fiber reinforced plastic in-line

Precision is required in rotor blade production: The individual glass fiber mats must be precisely aligned. For the first time, defects can be detected automatically, non-destructively and throughout the entire volume using a fully polarimetric radar - automatically during production.

Humans do not have X-ray vision. But it would sometimes be practical to be able to look inside things: For example, in the field of manufacturing rotor blades, which are made of glass-fiber-reinforced plastics and are used in wind turbines. In this process, various glass fiber mats are placed on top of each other, placed under vacuum and bonded with resin. However, if errors occur during the positioning of the glass fiber mats, for example if there are waves in a mat or the fibers are misaligned, this can have a negative effect on the mechanical properties of the manufactured component. However, such defects cannot be seen with the naked eye, especially if other glass fiber mats are stacked on top of them and the whole thing is vacuumed and pressed together in a very confined space. The only inspection option at present is manual inspection, whereby defects are only ever detected in the upper layer, if at all.

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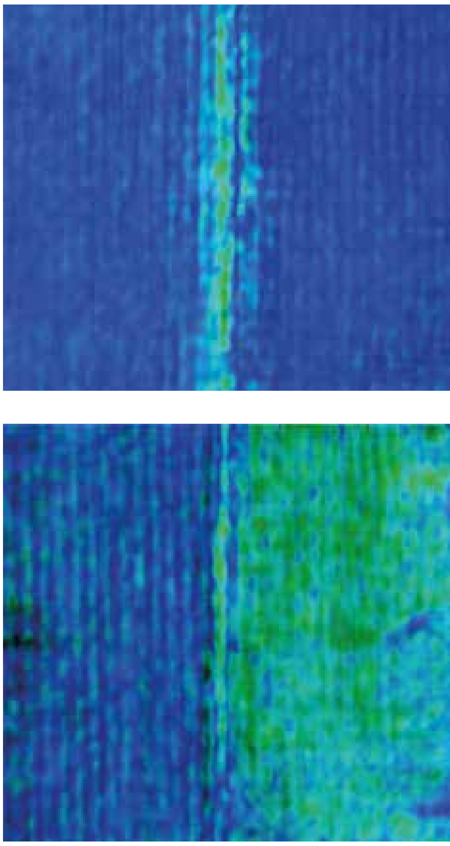
What remains closed to human vision, however, can be detected by a fully polarimetric radar: It detects defects already during production, non-destructively and automatically, across all layers. It was developed by researchers at Fraunhofer FHR in the publicly funded project Fiberradar (NRW-Leitmarkt), together with Aeroconcept GmbH, Ruhr University Bochum and Aachen University of Applied Sciences. The radar has a total of four channels, two for transmitting and two for receiving - instead of the usual one. This means that four possible combinations are available to elicit information from the rotor blade.

First successful measurements

A demonstrator has already been able to show what the system can do - even in a production environment. To do this, the researchers mounted a robotic arm on a mobile platform, which in turn holds the radar device. This setup scanned the entire blade tip, one-eighth of a rotor blade, and in this way allowed the fiber structure of the fiberglass composite to become visible. While the hardware components were developed by the partners, Fraunhofer FHR contributed its expertise in the algorithms needed for the evaluation. For example, the researchers succeeded in significantly increasing the image quality by adapting existing algorithms from polarimetric imaging to fiber composites on the one hand, and developing new algorithms for handling highly refractile materials specifically for this application on the other.

For the test measurements, Aeroconcept GmbH specifically introduced defects into the wing tip that are more likely to occur during



Output after decomposition process (top: fiber layer with undolation, bottom: with incomplete fiber layer on the left).

production: Misalignment defects, where fibers in a layer are misoriented. Undulations, where invisible waves occur in the layers. Half lengths, where the fiber layer stops in the middle of a layer. The system was able to reliably detect all of these errors. Two of the four channels in total, the cross-polarizations, scored well in detecting undolations and half-lengths. By combining the channels, the researchers can present the results to the user in a unified overview. The half-lengths were particularly easy to detect when the fiber direction changed, but when the direction was the same, the method also gave very good results. The system also detected angular errors very well: Defects of 10 and 20 degrees could be clearly detected even in deep layers - although the defects were covered by several layers. Thus, for the first time, defects could be detected via radar during the manufacturing process.

Production environment at Aeroconcept GmbH with rotor blade tip (approx. 1/8 of the finished blade).

Defective fiber layer with undolation.

Publications

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Education and Training

Lectures

WS 2021/2022

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)

Fröhlich, Andreas; Krist, Michael; Slavov, Angel: »Radarpraktikum«, 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: »Master-Praktikum Schaltungsdesign integrierter Hochfrequenzschaltungen mit CADENCE«, Ruhr-Universität Bochum (RUB)

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

Slavov, Angel: »Antennendesign für Radarsysteme«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Krebs, Christian: Lehrbeauftragte/r Leiterplattendesign, HS Koblenz

SS 2022

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)

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

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

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

Slavov, Angel: »Radarpraktikum«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Slavov, Angel: »Radar System Design und Anwendungen«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Supervised doctoral studies

Alshrafi, Wasim: »Grating Lobe Suppression in Microstrip Patch Uniform Linear Array Antennas Using Passive Structures«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Gemmer, Thomas: »Generalised Test-Zone Field Compensation«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Neuberger, Nadav: »Signal Processing for Space Surveillance Radar«, Universität Siegen

Panhuber, Reinhard: »AT: Partitioning of Radar Signals in Stationary and Moving Targets by use of Low-Rank and Compressed Sensing Methods«, Universität Siegen

Wagner, Simon: »Radar Target Classification via Sparse Decomposition«, Universität Siegen

Supervised master theses

Gräf, Michael: »Entwicklung eines Hochfrequenzsystems für intralogistische und luftgetragene Anwendungen«, Rheinische Fachhochschule Köln

Gütgemann, Sabine: »Modernes Leadership: Was kann es leisten, ist es operationalisierbar, und wie können Investition in die Entwicklung der Leadership-Kompetenz der Gruppenleitung gemessen werden?«, HS Koblenz

La Spada, Pietro: »Space debris detection and parameter estimation performance for BPEs with the TIRA system«, Università di Pisa

Leinz, Daniel: »Optimierung des Positionsmesssystems der Großantenne eines Weltraumbeobachtungsradars«, Technischen Hochschule Köln

Schepers, Maurice: »Entwicklung eines Transmitarrays zur frequenzselektiven Polarisationsdrehung«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Ta, Thanh Tam Julian: »Evaluierung des Einflusses der messenden Person auf die Erfassung von Mobilfunk-Immissionen mit einer isotropen Messsonde«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Uzair, Muhammad: »Design and Characterization of All-dielectric Metasurface for mm-wave Antenna«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Umashankar, Varsha: »Analysis of Phase Retrieval Algorithms on Planar Sampling Grids with a Sperical to Planar Wave Expansion Approach«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Weyland, Thomas: »Performance Analysis of 5G Mobile Networks as Illuminator of Opportunity for Passive Radar«, Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)

Committee Activities

Bertuch, T.

- IEEE Antennas and Propagation Standards WG P145: Mitglied
- European Conference on Antennas and Propagation (EuCAP) 2022: 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) 2022: Technical Review Committee
- IEEE Radar Conference 2022, 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) 2022: Technical Program Committee

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- 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 2022: Technical Program Member
- EuRad 2022: Technical Program Member
- EuRad 2022: Organisator und Vortragende des Workshops »Applications for advanced passive radar systems«
- IEEE RadarConf 2022: Track Chair
- IEEE RadarConf 2022: Vortragende des Tutorials »Passive radar on mobile platforms – from target detection to SAR/ISAR imaging«
- IET Radar 2022: Technical Review Committee
- International Radar Symposium (IRS) 2022: Technical Program Committee
- EUSAR 2022: Technical Program Member & Award Committee Member
- ARSI + KEO 2022 (ESA 7th edition of the Advanced RF Sensors and Remote Sensing Instruments workshop + 5th Ka-band for Earth Observation workshop): Technical Program Committee

Danklmayer, A.

- Deutsche Gesellschaft für Ortung und Navigation (DGON), Vorsitzender des Fachausschusses für Radartechnik
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- International Radar Symposium (IRS) 2022: Technical Program Committee Member
- IGARSS 2022, Kuala Lumpur, Malaysia: Scientific Committee Member
- EUSAR 2022, Leipzig Technical Program Committee Member
- 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

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- European Conference on Antennas and Propagation (EuCAP) Madrid: Mitorganisator, Exhibiton Chair
- European Conference on Antennas and Propagation (EuCAP) 2023, FlorenzMadrid: Mitorganisator, TPC chair
- Zentrum für Sensorsysteme (ZESS) 2022, Siegen: Vorsitzender Wissenschaftlicher Beirat
- IMA (Institut für Mikrowellen- und Antennentechnik e. V.): Vorsitzender
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Klare, J.

- International Radar Symposium (IRS) 2022: Technical Program Committee
- European Microwave Week (EuMW) 2022: Technical Review Committee
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Knott, P.

- Deutsche Gesellschaft für Ortung und Navigation (DGON): Mitglied im Wissenschaftlichen Beirat, Vorsitzender Fachausschuss Radartechnik
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- Deutsche Gesellschaft für Wehrtechnik e.V.: Mitglied im Beirat Brüssel - neu
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- IEEE AESS QEB Editor-in-Chief 2022-2023
- NATO STO SET-ET-128 »Open Data RFT/OT Initiative«: Chair

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
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- European Defence Agency: CapTech Member
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- International Microwave Symposium (IMS 2022), Denver: Technical Program and Review Committee
- European Microwave Week (EuMW) 2022, Mailand: Technical Program Committee
- IEEE BiCMOS and Compound Semiconductor Integrated

Circuits and Technology Symposium (BCICTS 2022), Phoenix: Technical Program Committee, Co-Chair for MM-Wave & THz ICs

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- EDA CapTech Radar: German Governmental Expert
- BMVI Nationale Vorbereitungsgruppe zur WRC-23 (NVG23): Mitglied
- ETSI TGUWB: Mitglied

Walterscheid, I.

- IEEE IGARSS 2022: Scientific Committee
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- IEEE (Institute of Electrical Electronics Engineers): Senior Member
- VDE-ITG: Member

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- NATO STO Group SET-287 »Characterization of Noise Radar« : Chair
- International Radar Symposium (IRS) 2022: 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) 2022: Technical Review Committee und Session Chair
- IEEE Antennas and Propagation Standards WG P2816: Mitglied
- EurAAP Working Group »Active Array Antennas« (WGA3): Mitglied
- EMWT'22 Specialist Meeting on Electromagnetic Waves and Wind Turbines: Technical Committee

Weiß, M.

- EUSAR 2022, Leipzig: Technical Chair, EUSAR Executive
- IGARSS 2022, Kuala Lumpur, Malaysia: Technical Program Member
- European Radar Conference (EuRAD) 2022: Technical Program Member
- International Radar Symposium (IRS) 2022: Technical Program Member
- Signal Processing Symposium (SPSympo) 2022, Lodz/online: Technical Program Member
- ICARES 2022, Yogyakarta, Indonesia, 24-25 November 2022: Technical Program Member
- NTSP 2022, Demänovská Dolina, Slovakia, 12-14 October 2022: Technical Program Member

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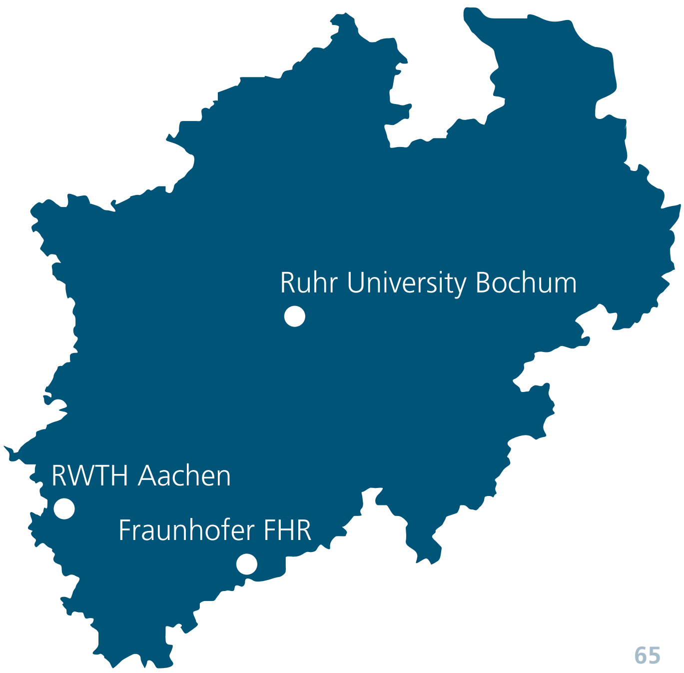

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