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FRAUNHOFER INSTITUTE FOR HIGH FREQUENCY PHYSICS AND RADAR TECHNIQUES FHR

ANNUAL REPORT 2018

The research with frozen radar receivers promises significant improvements in sensitivity.

ANNUAL REPORT
2018

PREFACE

Dear Friends and Partners of Fraunhofer FHR,
Dear Readers,

looking back at 2018 and our many research activities, our business unit »Space« takes center stage once again: The world paid close attention as we monitored the re-entry of the space station Tiangong-1 into the Earth's atmosphere with our space observation radar TIRA in early April. Our analyses and radar images not only helped the German Space Situational Awareness Center but also ESA and a worldwide network to improve their predictions for the location and date of the crash. Due to the international relevance, our radar images of Tiangong-1 were published in the media around the word (more on page 50).

The images taken of the French satellite MicroSCOPE in October were another highlight. For the first time, the French space agency tested a passive deorbiting system: When the mission ended, brake sails were released, which will reduce the satellite's orbital lifetime by two thirds. With TIRA's radar images, we were able to prove that the sails had unfolded correctly and that they would fulfill their purpose (more on page 52).

Both results are excellent examples that TIRA and its unique capacities will remain an indispensable sensor for Germany and the global community.

Our space observation sensors were also the main focus during the ILA Berlin Air Show at the end of April. In addition to our own Fraunhofer booth, we also had the opportunity to share the booth of the German Space Situational Awareness Center of the German Armed Forces and the booth of the German Federal Ministry for Economic Affairs and Energy, where even Federal Defense Secretary Ursula von der Leyen and Federal Secretary of Economics Peter Altmaier showed their special interest in our capacities with the new space surveillance radars GESTRA and TIRA (more on page 13).

After 19 years on Fraunhofer FHR's Advisory Board as well as its Scientific Advisory Board (with more than 15 years as its chairman), Prof. Dr. Hermann Rohling (TU Hamburg-Harburg) retired on June 29th and passed his position on to his successor Gunnar Pappert (Diehl Defence). We would like to thank him for his many years of commitment and are always happy to remember his friendly and accessible personality. His dedication was extraordinary, in particular when FGAN was integrated into the Fraunhofer-Gesellschaft, when he campaigned for FHR's interests together with the Advisory Board. We wish him all the best for the future (more on page 10).

There were personnel-related news within the institute as well: On January 1, 2018, Prof. Dr. Daniel O'Hagan officially assumed the management of the department »Passive Radar and Anti-Jamming Techniques« (PSR). He had already worked for Fraunhofer FHR as a scientist and project manager from 2009 to 2014. He then took on the position as professor at the University of Cape Town, South Africa, before returning to Fraunhofer FHR as a Head of Department. We are happy to welcome back this expert on passive radar with his excellent global network and wish him much success in his new role at our institute.

In the business unit Traffic, our business unit spokesman Dr. Andreas Danklmayer is now placing his full capacities at the disposal of our customers and partners. He will introduce himself in the interview on page 20.

Our staff with their diverse range of skills and their specialist knowledge are the most important element of successful work. To make even better use of these valuable assets we created the staff function Personnel Development at the institute as of 1 August 2018. Hanne Bendel, who has been with the institute since 2013, took on this challenging task. With this, we aim to provide our staff with even better and more targeted assistance and support when it comes to developing their careers.

In 2018, our industrial project PARASOL achieved a very positive result: We received the accreditation from German Air Traffic Control (DFS) for the passive radar systems. With this, there is nothing standing in the way of the widespread use of the air traffic surveillance radar for wind turbines (more on page 64).

We would like to take this opportunity to thank our supporters on the federal and state levels as well as our partners and customers for their trust and our members of staff for their loyal and constructive collaboration.

This Annual Report 2018 presents a selection of our many research projects. We invite you to gain new insights and wish you a stimulating read!

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New Head of the PSR Department

As of January 1, 2018, Prof. Dr. Daniel O'Hagan took over the management of the department »Passive Radar and Anti-Jamming Techniques« (PSR). He had already worked at Fraunhofer FHR from 2009 to 2014, before taking on the position as professor at the University of Cape Town, South Africa and now returning to the institute.

Berlin, Germany, 18.1.2018

Juliane Rama Wins the Friedrich Wilhelm Gundlach Award

Dr. rer. nat. Juliane Rama (dep. ISS) received the Friedrich Wilhelm Gundlach Award, TU Berlin for her master thesis »Theoretische Synthese der SAR-Trajektorie eines 3D-Radarscanners im Millimeterwellenbereich« (Theoretical synthesis of the SAR trajectory for a millimeter wave 3D radar scanner).

Bonn, Germany, 20.-22.2.2018

Applied Research for Defense and Security in Germany

Fraunhofer FHR presented the newest technologies and applications for the defense and security area, for example the PAMIR-Ka system for airborne radar imaging or the space observation radars TIRA and GESTRA.

Wachtberg, Germany, 1.4.2018

Radar Images of Tiangong-1 Go Around The Word

The world paid close attention as Fraunhofer FHR monitored the re-entry of the Chinese space station Tiangong-1 into Earth's atmosphere. The unique radar images were published in the national and international press (more information on page 50).

Cologne, Germany, 20.-23.3.2018

Anuga FoodTec

At the leading trade show of the food industry, we teamed up with five Fraunhofer institutes to showcase our FoodInSpector, which is capable of detecting contaminants in packaged food.

The Institute Directors Prof. Knott and Prof. Heberling welcome the guests at the 8th Wachtberg-Forum inside the space observation radar TIRA.

Wachtberg, Germany, 27.4.20178

Girls' Day

For the 18th time, girls of different age groups visited Fraunhofer FHR. They built an electronic assembly, got to know an electronics laboratory, programmed a Lego robot and found out what a precision mechanic does in a series of workshops. Naturally, to close off the visit, the group went to see the »ball«.

Hannover, Germany, 23.-27.4.2018

Hannover Messe

Within the scope of the Research Fab Microelectronics Germany (FMD), we presented our know-how in the area of radar antenna production at the shared Fraunhofer booth, specifically in the production of dielectric lenses using 3D printing.

Berlin, Germany, 25.-29.4.2018

ILA Berlin Air Show: Fraunhofer FHR On Exhibit at Four Booths – Premiere of the GESTRA Film

(See detailed article on page 12)

Wachtberg, Germany, 8.5.2018

Quality Management Audit for ISO Certification of Our Administration Successful

To improve our processes and our transparency, all administrative procedures were documented in a quality management handbook (QMH) and certified by TÜV Süd.

Bonn, Germany, 18.5.2018

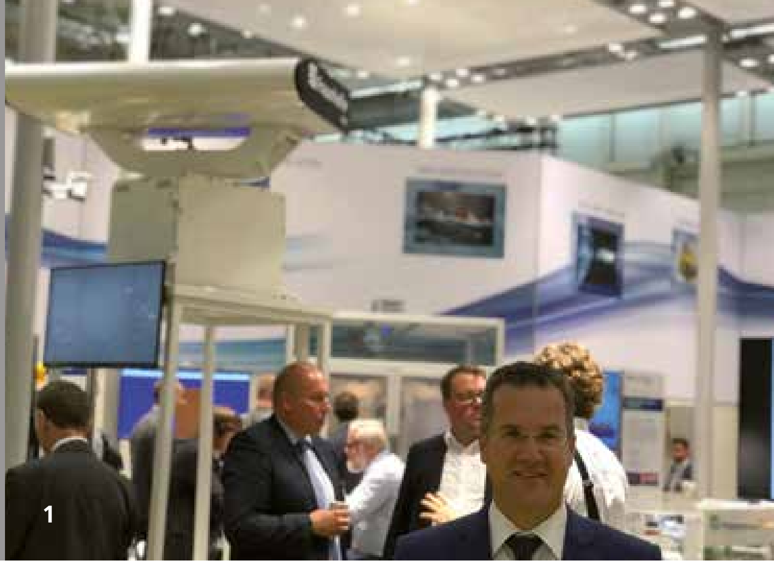
Bonn Science Night

Fraunhofer FHR attended the Science Night with its own booth and a presentation on the subject of »Radar Cycles«, focusing on the areas of space observation and non-contact, non-destructive testing.

Aachen, Germany, 4.-7.6.2018

12th European Conference on Synthetic Aperture Radar (EUSAR): Best Poster Award for Dr. Walterscheid, Philipp Wojaczek, and Dr. Diego Cristallini

(See detailed article on page 14)



Wachtberg, Germany, 8.6.2018

Researchers from MIT Lincoln Laboratory, USA, visited Fraunhofer FHR and its High Power Radar System TIRA

Dr. Joseph Usoff is chief scientist for the Haystack Ultrawideband Satellite Imaging Radar (HUSIR), a space observation radar comparable to TIRA in size and performance. This made the scientific exchange between the two parties very helpful.

Bonn, Germany, 20.-22.6.2018

International Radar Symposium (IRS)

(See detailed article on page 16)

Wachtberg, Germany, 28.6.2018

Wachtberg-Forum

Our popular technology demonstration took place at the location of our headquarters in Wachtberg, drawing in a record number of more than 200 attendants. This year, the main topics were both drone detection as well as drones as sensor carriers (more on this at www.fhr.fraunhofer.de/wachtberg-forum).

Remagen, Germany, 13-20.7.2018

10th International Summer School on Radar/SAR

For the 10th time already, about 50 participants from around the world came to the Rhineland to attend the International Summer School on Radar/SAR. This event is designed for young scientists in the radar field. Besides presentations from international radar experts, the event featured intense workshops and an engaging accompanying program that offered plenty of networking opportunities.

Wachtberg, Germany, 23.7.2018

Daniel Behrendt Appointed as the New Spokesman for the Business Unit Production

To strengthen our business unit Production, Daniel Behrendt was appointed as the new full-time Business Unit Spokesman Production.

Wachtberg, Germany, 1.8.2018

Focus On Staff: New Staff Function Personnel Development at Fraunhofer FHR with Hanne Bendel

The creation of the Personnel Development staff function aims to assist and support staff members when it comes to developing their careers. Hanne Bendel took on this challenging task.

Wachtberg, Germany, 23.8.2018

Award: IET Premium Award 2018 for Fraunhofer FHR Scientists Dr. D. Cristallini and G. Bournaka

The authors Francesca Filippini, Fabiola Colone (University of Rome), Dr. Diego Cristallini, and Georgia Bournaka (dep. PSR) were honored with the 2018 Premium Award for Best Paper in the journal »IET Radar, Sonar & Navigation« for the publication of »Experimental results of polarimetric detection schemes for DVB-T-based passive radar«.

Hamburg, Germany, 4.-7.9.2018

SMM Trade Fair

At the shared Fraunhofer booth of the maritime trade fair SMM, Fraunhofer FHR and its partners presented the new sea rescue radar SEERAD. This system is capable of locating individuals in the water over large distances, while also using significantly cheaper transponders than current systems.

Bonn, Germany, 13.9.2018

Company Run in Bonn

More than 40 Fraunhofer FHR and FKIE staff members teamed up for charity to participate in the 12th Company Run in Bonn.

Bonn, 26.09.2018

Award: Oliver Grenz Honored With AFCEA Student Award

Oliver Grenz received a second prize of the AFCEA Student Awards and with this prize money in the amount of 3000 Euros for his master thesis »Verlustoptimierung einer breitbandigen, doppelt polarisierten CBSP-Antenne im L-Band mit Betrachtung

der Kreuzpolarisationsentkopplung, Fertigungsaspekten und Phased-Array Tauglichkeit« (Loss optimization of a broadband, dual-polarized CBSP antenna in the L-band considering the cross polarization discrimination, production aspects, and phased array suitability) within the scope of the GESTRA research project.

Madrid, Spain, 25.-27.9.2018

European Microwave Week (EUMW)

Together with the Dutch research organization TNO, Fraunhofer FHR and IAF exhibited their new technologies in the area of millimeter and terahertz systems. They showcased the cognitive radar systems for smart driver assistance systems and the radar target generator ATRIUM.

Bremen, Germany, 1.-5.10.2018

69th International Astronautical Congress IAC

After 15 years, the annual international aerospace trade fair returned to Germany. Together with the Fraunhofer Space Alliance, the institute exhibited its space observation capabilities with TIRA and GESTRA.

Munich, Germany, 13.-16.11.2018

Electronica Trade Fair

Fraunhofer FHR participated in the shared Fraunhofer booth within the scope of the FMD. The topics centered on the non-contact monitoring of vital parameters and drone-based high-resolution radar imaging.

Wachtberg, Germany, 15.11.2018

ESA European Space Talks

More than 280 events in 27 countries were held on the occasion of the Space Talks initiated by the European Space Agency. At Fraunhofer FHR, the event was quickly booked out at and included the ESA space debris expert Dr. Holger Krag as well as 60 participants.

1 *Business Unit Spokesman Traffic, Dr. Danklmayer, in front of our SMM trade fair booth in Hamburg with our new maritime radar.*

2 *Oliver Grenz (3rd person from the left) won an AFCEA student award.*

3 *At the European Space Talks, researchers of Fraunhofer FHR and the ESA reported on the current space debris situation.*

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FAREWELL TO PROF. ROHLING AS LONG-TERM CHAIRMAN OF THE ADVISORY BOARD

An era came to end on June 29., 2018: Prof. Hermann Rohling said farewell and retired. He had been part of the advisory board since 1999, having been its chairman for more than 15 years. Gunnar Pappert was unanimously elected as his successor.

Each Fraunhofer institute has an advisory board consisting of members from politics, business, and science. These members advise the institute regarding strategic questions and important institute developments. The board meets at least once a year. In 2018, we saw a very special change. After more than 15 years as its chairman and almost 20 years on Fraunhofer FHR's advisory board, Prof. Dr. rer. nat. Dr. h. c. Hermann Rohling (TU Hamburg-Harburg) passed the chairmanship on to his successor Gunnar Pappert (Diehl Defence).

The distinguished radar researcher and entrepreneur Prof. Rohling supported Fraunhofer FHR as an advisor for almost 20 years. When he was appointed to the Scientific Advisory Board in 1999, he had just taken on management of the Institute of Communications at the Hamburg University of Technology. Before that, he had worked in the industrial sector and at several other universities. His extensive experience and his international network were always an enriching addition to the institute. It was especially during the many years of the transition period from FGAN to the Fraunhofer-Gesellschaft when he was extraordinarily committed to the institute, making it possible to create an excellent framework for the start in the new organization. This also laid an optimal foundation for the successful development of our institute's history.

His involvement in the German Association of Position Finding and Navigation (Deutsche Gesellschaft für Ortung und Navigation, DGON) and the creation of the International Radar Symposium (IRS) produced a large network, especially in Central and Eastern Europe, from which the institute was able to profit as well. There is a reason why Prof. Dr. Knott took over the conference chair of the IRS from Prof. Rohling.

The institute owes a lot to Prof. Rohling, and directors as well as the entire staff of the institute wish him all the best. Gunnar Pappert has already been a member of Fraunhofer FHR's Advisory Board since 2009. His collaboration with the institute, however, began many years even before that. After studying communications engineering with a focus on radar engineering at the Technical University of Munich, he began working as a High Frequency Development Engineer in the business unit Defense at Diehl Defence. In this role, we have already had a number of projects with intense collaboration in the development of radar sensors and in the field of signature measuring campaigns.

After being in charge of different function in setup and process organization at Diehl Defence, Mr. Pappert became Head of Quality Management in 2006 and has also been Site Manager at Diehl Defence Röthenbach since 2013. Since 2015, Mr. Pappert has been managing the army systems product area.

It is especially in the area of quality management and quality assurance where we have seen a significant rise in the demands placed on the institute due to the continuously increasing number of industrial projects. A targeted and systematic strategy process as well as a successful market presence are very important for the institute. Mr. Pappert is the ideal chairman with his experience in product management, quality management, strategy processes, and marketing to advise and support the institute on a broad scale in the future.

Fraunhofer FHR is looking forward to continuing this prolific cooperation and the institute management wishes Mr. Pappert much success in his new role.

The Institute Directors Prof. Knott (l.) and Prof. Heberling (r.) say goodbye to Prof. Rohling (2. f. l.) and welcome Gunnar Pappert (2. f. r.) as the new chairman of the advisory board.

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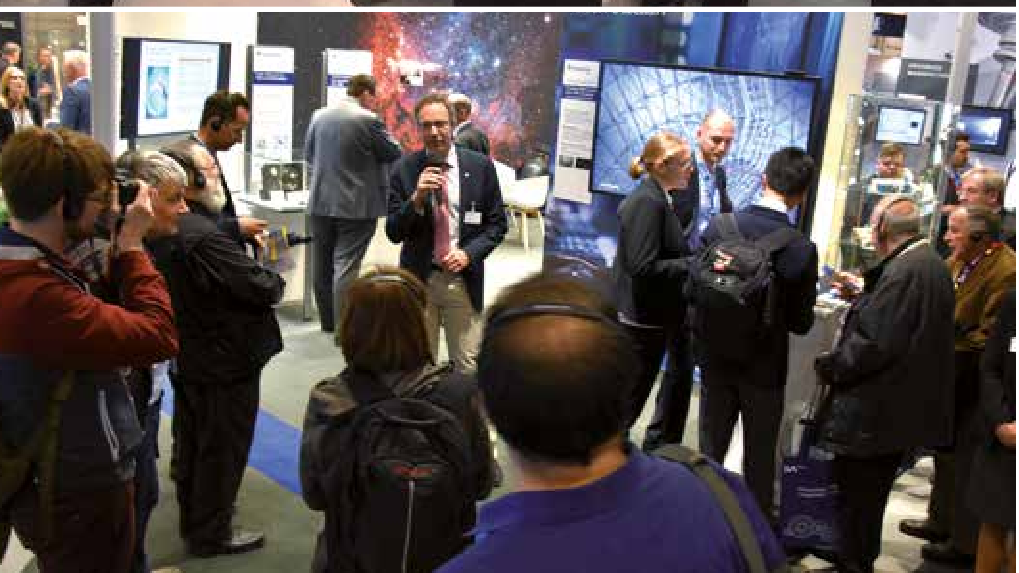

ILA BERLIN AIR SHOW: FRAUNHOFER FHR ON EXHIBIT AT FOUR BOOTHS

Fraunhofer exhibited its radar sensors at four booths at the ILA Berlin Air Show from April 25 to 29. Our film about the space surveillance radar GESTRA also had its premiere at the show.

An ever-increasing amount of space debris is putting satellites at risk in low Earth orbit. However, their roles in the fields of telecommunications, navigation, or weather forecasting are essential to our society. That is the why Fraunhofer FHR is developing radar-based systems capable of detecting, tracking, and cataloging even the smallest of debris. With highly accurate orbit data of as many of these objects as possible, satellite operators are better able to plan evasive maneuvers and avoid destructive collisions. Together with its partners, Fraunhofer FHR presented its complementary radar systems TIRA and GESTRA at four booths of the aerospace trade fair ILA Berlin Air Show from April 25 to 29, 2018: Fraunhofer-Gesellschaft in hall 2, Space Pavilion in hall 4, Space Situational Awareness Center in hall 3, and the Federal Ministry of Economics and Energy BMWi In hall 2.

Satellite-based services are indispensable for modern societies – and with this also for our knowledge of the situation in orbit. To obtain information about the so-called space situational awareness, politics, space agencies, and satellite operators are currently undertaking a wide range of efforts. Due to the high speed of satellites and other space objects, even particles with the size of only one centimeter can have a major disruptive force – in every sense of the word – and contribute to the intensification of the situation in space.

Radar Warns of Debris in Space and Helps in Case of Damages

The Tracking and Imaging Radar TIRA enables the identification and technical analysis of satellites in addition to orbit and damage analysis. With the German Experimental Space Surveillance and Tracking Radar GESTRA, space surveillance radar with leading-edge technology is being developed to create a catalogue of space debris in the near-Earth region.

For this reason, at the ILA Berlin Air Show, our systems also attracted the attention of two German federal secretaries. Dr. Gerald Braun (DLR) informed the Federal Secretary of Economics, Peter Altmaier, about GESTRA at the booth of the Federal Ministry of Economics. The project is supported by the Federal Ministry of Economics based on the resolution of the German Federal Parliament and coordinated by the DLR Space Administration. For its implementation, Fraunhofer FHR is working in close cooperation with the German Space Situational Awareness Center in Uedem, which will operate the system.

After her press conference, the German Secretary of Defense Ursula von der Leyen visited the booth of the German armed forces, where the German Space Situational Awareness Center was also present. Here, Fraunhofer FHR showed models of GESTRA and TIRA. The two Fraunhofer FHR systems make it possible for the German Space Situational Awareness to collect the necessary information about satellites and space debris, regardless of the weather and the time of day. The Federal Secretary of Defense was highly interested in the capacities made available to the German Space Situational Awareness Center thanks to the two high-power sensors. She was especially impressed by the strategic expandability of the GESTRA concept concerning distributed phased array-based space surveillance radars. Fraunhofer FHR will play a leading role in the further development and substantiation of this concept, which Dr. Braun presented as unique in the world.

German Federal Secretary of Defense Ursula von der Leyen and Federal Secretary of Economics Peter Altmaier visited our booths at the ILA Berlin Air Show.

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California Institute of Technology
EUSAR 2018


EUSAR 2018


Fraunhofer
TIRA

EUROPEAN CONFERENCE ON SYNTHETIC APERTURE RADAR (EUSAR)

With more than 450 scientists from 32 countries, the international conference on radar imaging in Aachen, Germany from June 4 to 7, 2018 was the world's largest conference in this field. Dr. Andreas Brenner of Fraunhofer FHR was General Chairman.

Radar images of Earth from the air, from space or from objects in space offer unique advantages: High-resolution images can be created from a distance of hundreds of kilometers – regardless of weather or daylight conditions. For instance: these images can be detailed maps of the Earth's surface for cartography or precise images of satellites, as was the case with the re-entry of the Chinese space station Tiangong-1.

What are the newest developments and applications in the radar imaging area? This is the question the 450 scientists from 32 countries answered at the 12th European Conference on Synthetic Aperture Radar (EUSAR) in Aachen in early June. The conference takes place every two years. It is organized by the German Association for Electrical, Electronic & Information Technologies (VDE) and scientifically supported by the Fraunhofer-Gesellschaft, the German Aerospace Center DLR, Airbus, and Hensoldt. In 2018, the conference was chaired by Dr. Andreas Brenner, Head of Department at Fraunhofer FHR.

With more than 250 contributions in 50 sessions, the conference covered the entire spectrum of the subject. The presentations by leading researchers from the US were especially noteworthy: Dr. Paul Rosen (NASA JPL) presented the newest technologies and results for satellite-based earth observation, and Dr. Joseph Usoff (MIT Lincoln Laboratory) showed the capacity of the high-power Haystack radar (HUSIR), which belongs to the world's most powerful radar systems in the Earth observation sector, together with Fraunhofer FHR's high-power TIRA radar system. Radar is the only sensor that offers the capability of detecting the smallest of space debris from the Earth's surface and of creating high-resolution images of space objects, as was the case at Easter 2018, when Fraunhofer FHR monitored the re-entry of the Chinese space station Tiangong-1. Researchers of Fraunhofer FHR also contribute to this subject.

Best Poster Award for Fraunhofer FHR Scientists

On the last day of the EUSAR conference in Aachen, prizes were awarded for the best contributions: Fraunhofer FHR scientist Dr. Ingo Walterscheid and his institute colleagues Philipp Wojaczek and Dr. Diego Cristallini as well Ashley Summers (DSTG, AUS) won the »Best Poster Award« for the paper »Challenges and first results of an airborne passive SAR experiment using a DVB-T transmitter«. The institute management congratulated the award winners for their outstanding success.

The presented project »Passive SAR« investigates how non-cooperative illuminators (here DVB-T) can be used for radar imaging and concealed reconnaissance. The paper describes the challenges and the first results of a measuring campaign in which television signals (DVB-T) were received and recorded on board of the microlite aircraft »Delphin« using a PCL receiver. The subsequent signal processing successfully provided the first radar Images.

The next EUSAR will take place from June 15 to 18, 2020 in Leipzig, Germany. For updated information, please visit www.eusar.de.

Dr. Brenner, Dr. Usoff (MIT Lincoln Laboratory) and Dr. Rosen (NASA JPL) opened the EUSAR in Aachen. The US researchers visited our space observation radar TIRA after the conference.

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INTERNATIONAL RADAR SYMPOSIUM IRS CELEBRATES ITS 20TH ANNIVERSARY IN BONN

Every year, experts from around the world exchange the newest insights on radar research at the International Radar Symposium IRS, opening up this promising technology for modern applications.

In 2018, the symposium organized by the German Association of Position Finding and Navigation (Deutsche Gesellschaft für Ortung und Navigation, DGON) and the Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR celebrated its 20th anniversary in Bonn. The four-day symposium, chaired by Prof. Dr. Peter Knott, Executive Director of Fraunhofer FHR, kicked off on June 19., 2018, with a visit to the institute in Wachtberg und its highly visible space observation radar TIRA.

Radar systems are capable of quickly and reliably detecting the smallest of movements even at great distances and with poor visibility. Thus, they are predestined to provide a higher level of safety in areas such as road, ship, and air traffic, manufacturing and the protection of people. Radar research is continuously making these complex systems smaller, lighter, and more efficient in terms of costs and other resources such as energy requirements, computing power, and storage capacity. Increasingly intelligent sensors that adapt to the individual tasks and relieve the user also form a part of the current research.

At the International Radar Symposium from June 19. to 22., 2018, approximately 300 scientists discussed the complex technology as well as the possible applications with more than 150 contributions along with a technical exhibition. Among others, the agenda also included new techniques for signal and data processing. The talks focused on passive radar – which does not emit any signals by itself, instead using the reflections of existing signal sources like TV and mobile transmitters – cognitive radar, and new signal generation methods for the precise and effective control of the systems.

Other topics at the symposium addressed how radar techniques can be used to improve the detection capabilities of drones and air traffic control, to delivery early and reliable storm warnings in meteorology, or to provide for reliable driver assistance systems, for example. Many technical trends require increasingly precise and intelligent systems. With this, radar technology is becoming more important both for military as well as civil tasks. The researchers at Fraunhofer FHR and around the world are aiming to make this technology more usable for businesses and organizations – and thus also for the end user. This is why the date for the next International Radar Symposium has already been set: It will take place in Ulm, Germany, from June 26 to 28, 2019.

Christian Hülsmeyer Award for Professor Rohling

Thanks to the technological progress, radar is becoming increasingly important for numerous applications. The basis for this is a pronounced pioneering spirit in research. The program committee of the Radar Symposiums IRS once again paid tribute to this in 2018 by awarding the Christian Hülsmeyer Award. Chaired by Prof. Dr. Knott, the committee honored Dr. Hermann Rohling from the Hamburg University of Technology for his work in the field of radar system design and development as well as for his commitment to teaching und his contributions to facilitate networking in the radar community, including co-founding the IRS International Radar Symposium. Participants from 38 countries attended the award ceremony at the IRS 2018.

On the occasion of the 20th International Radar Symposium (IRS) in Bonn, the participants also visited Fraunhofer FHR's space observation radar TIRA in Wachtberg.

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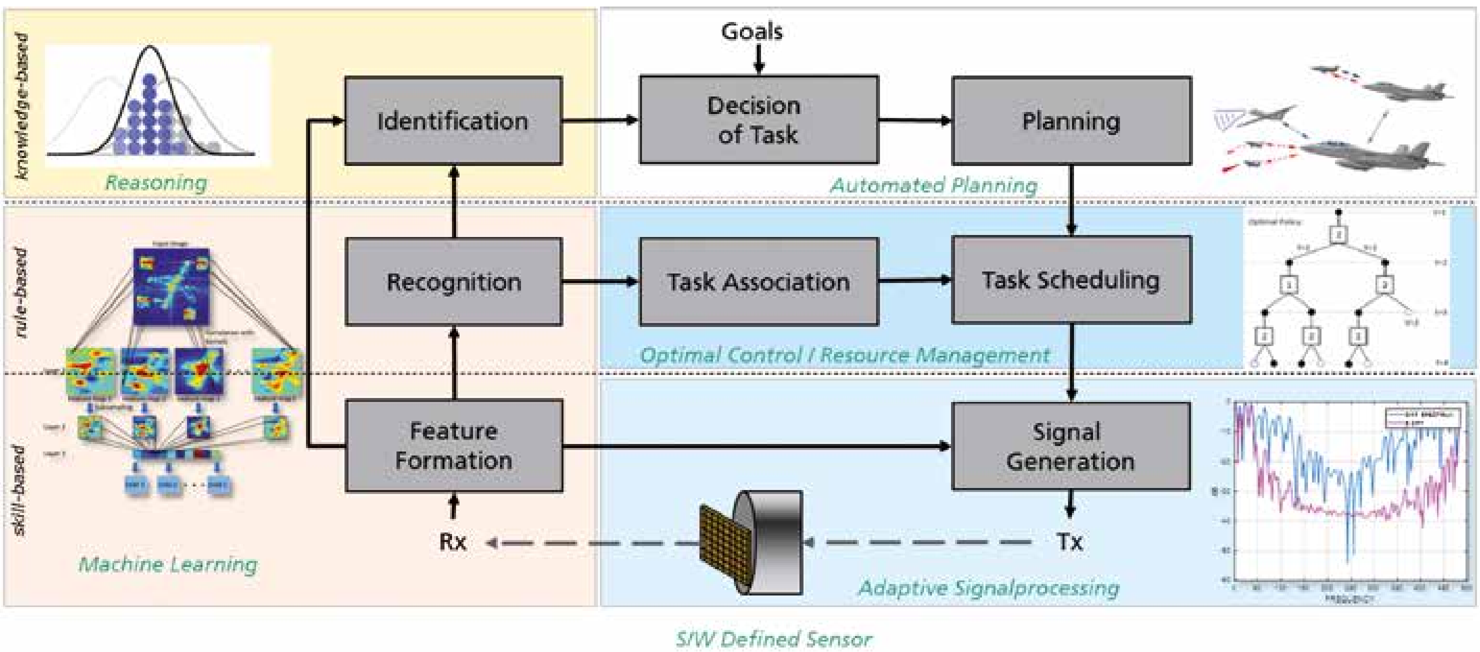
FROM THE INSTITUTE



EDA WORKSHOP »AI AND COGNITIVE TECHNOLOGIES FOR RADAR, COMMS AND EW«

From December 3 to 4, 2018 a workshop was held at the European Defence Agency (EDA) in Brussels on the subject of »Artificial Intelligence and Cognitive Technologies for Radar, Communication and Electronic Warfare«. With 64 participants from the CapTechs Radar and Information Technology, the event drew great response. The 22 presentations in total were subdivided into four main topics.

The increasing expansion of the radio frequencies used by both radar as well as communication systems requires a more intelligent use of the available spectrum as well as excellent coordination of the disciplines, which have frequently worked separately in the past. In particular, the now established communication technology of cognitive radio can be used as a template for radar as well as electronic warfare. That is why the NATO Industrial Advisory Group came up with the idea of organizing a cross-CapTech workshop on this subject.

The concept of cognitive radar provides a real-time adaptation of all radar parameters to scene, electromagnetic environment and mission objectives. Artificial intelligence (AI), machine learning, and numeric optimization processes are used for the technical implementation. The participants from industry and research emphasized the growing importance of cognitive processes to control modern, software-defined multifunctional high frequency (HF) systems and presented the newest results and perspectives concerning the operational use.

The first main topic of »Cognitive Multifunctional HF Architecture« shed light on different system architectures for signal and information processing in active electronically scanned array (AESA) systems. The image below shows the cognitive radar architecture of Fraunhofer FHR, which works on three levels of abstraction in analogy to a model of human cognition. It became evident that the transition from current, adaptive radar systems to cognitive ones occurs gradually, characterized particularly by increasing degrees of automation and learning capacities.

The topic block »Coexistence and Spectrum Management« addressed the specific challenges associated with a densely occupied electromagnetic spectrum driven primarily by the increasing demand for bandwidth in mobile communication (5G). Military radar systems also have to meet these new requirements, needing to be frequency-agile in their operation.

The topic block »Machine Learning« was mostly marked by the application of Deep Learning processes for automatic target classification. However, a trend was also noticeable to replace general statistical signal processing procedures by data-driven approaches.

In the last topic block, cross-thematic artificial intelligence approaches and sensor fusion were explained. It was revealed that the consideration of contextual information as well as explainable AI can make significant contributions to situational awareness and to the certification capability of cognitive sensor systems.

Due to the disruptive potential and the wide range of applications, the workshop turned out to be an important contribution to the European cooperation in this field.

The workshop »Artificial Intelligence and Cognitive Technologies for Radar, Communications and Electronic Warfare« was organized by Fraunhofer FHR and took place at the EDA in Brussels from December 3 to 4, 2018.

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INTERVIEW

RADAR SENSORS – ALWAYS ON BOARD!

On land, on water, or in the air: Radar is a key sensor for more autonomy and safety in traffic. That is why Dr. Andreas Danklmayer, as the first point of contact, quickly connects customers and partners in industry with the right experts at Fraunhofer FHR.

Dr. Danklmayer, you have been the full-time spokesman of the business unit Traffic and with this, the face of Fraunhofer FHR for customers and partners in the traffic industry since the beginning of 2019. Why is the institute taking this step?

All branches of the transportation industry are facing major new challenges: In road traffic, the focus is on modern driver assistance systems reaching all the way to autonomous driving. We are especially dealing with the higher safety requirements on the increasing shipping and air traffic, and in rail traffic there are new challenges, for example due to the higher utilization of the freight transport systems. The demand for reliable and efficient technologies is growing. We want to make the search for suitable solutions easier for our customers and partners with a direct point of contact for the business unit Traffic.

Fraunhofer FHR researches and develops radar and high frequency technology. How can this contribute to solving these new challenges?

Cars that are supposed to drive autonomously or package drones that are supposed to fly autonomously have to be able to reliably recognize traffic routes and obstacles in any weather and light condition. Radar is capable of accurately measuring objects and distances regardless of the light, even in dust or fog. This makes radar indispensable for navigation and detection tasks. Landing helicopters can also rely on radar when swirling dust obscures visibility to the ground, and container ships can use radar to track each other as well as smaller objects in the water, e. g. water sportsmen and locate them anytime. In addition, radar can penetrate objects and is therefore very interesting, for example for railway companies in order to inspect track beds.

Radar has long been known in traffic: Many cars have radar on board and everyone knows the rotating antennas on ships. What does the Fraunhofer FHR offer here?

Yes, radar sensors with Fraunhofer FHR antenna designs have already been built into different types of vehicles more than 30 million times. But the requirements are changing: An increasing number of the driving public has to reach their destination safely with increasingly autonomous vehicles. In doing so, the sensors should be as small and as energy and cost-efficient as possible. And they should not interfere with each other. Nowadays, modern cars are equipped with up to 20 antennas, military platforms with even more than that! On the one hand, this calls for entirely new antenna concepts, such as miniaturized sensors that are perfectly integrated into the vehicle structure of cars or efficient, non-rotating low-maintenance antennas on ships. And on the other hand, signal processing has to become more intelligent, as it has to be able to detect the environment faster and better, while the system constantly adapts to the situation, in alignment with other sensors. With our enormous and broad range of expertise in terms of high frequency systems, electromagnetic simulation, signal processing, and classification, we are able to offer our customers comprehensive solutions tailored exactly to their needs, from consultation to system design and up to testing prototypes and small-scale production.

As the business unit spokesman, you mediate between industry and the experts at the institute. What is the biggest challenge involved with this?

Of course, it helps that I myself have been working in the business unit Traffic for a long time now, both as a scientist and as a part-time business unit spokesman and also because I know the technology and the industry very well. The challenge is to stay on the ball in both directions: being close to the pulse of the industry as well as professionally keeping track of things. This is the only way for me to bundle our know-how internally, uncover and recognize the needs of our clients, and communicate how we can help with radar.

With this new role, you are passing up on your own research activities. Will you miss that?

Well, Joseph von Fraunhofer is my role model here: He was a researcher and an entrepreneur as well. My spirit of research has not diminished because of my new role. And it shouldn't so that I can remain a competent contact person for our customers. The wheel keeps turning and I will always be excited about the newest results in research. I see it as a mission to feed important impulses from the economy into Fraunhofer FHR research planning.

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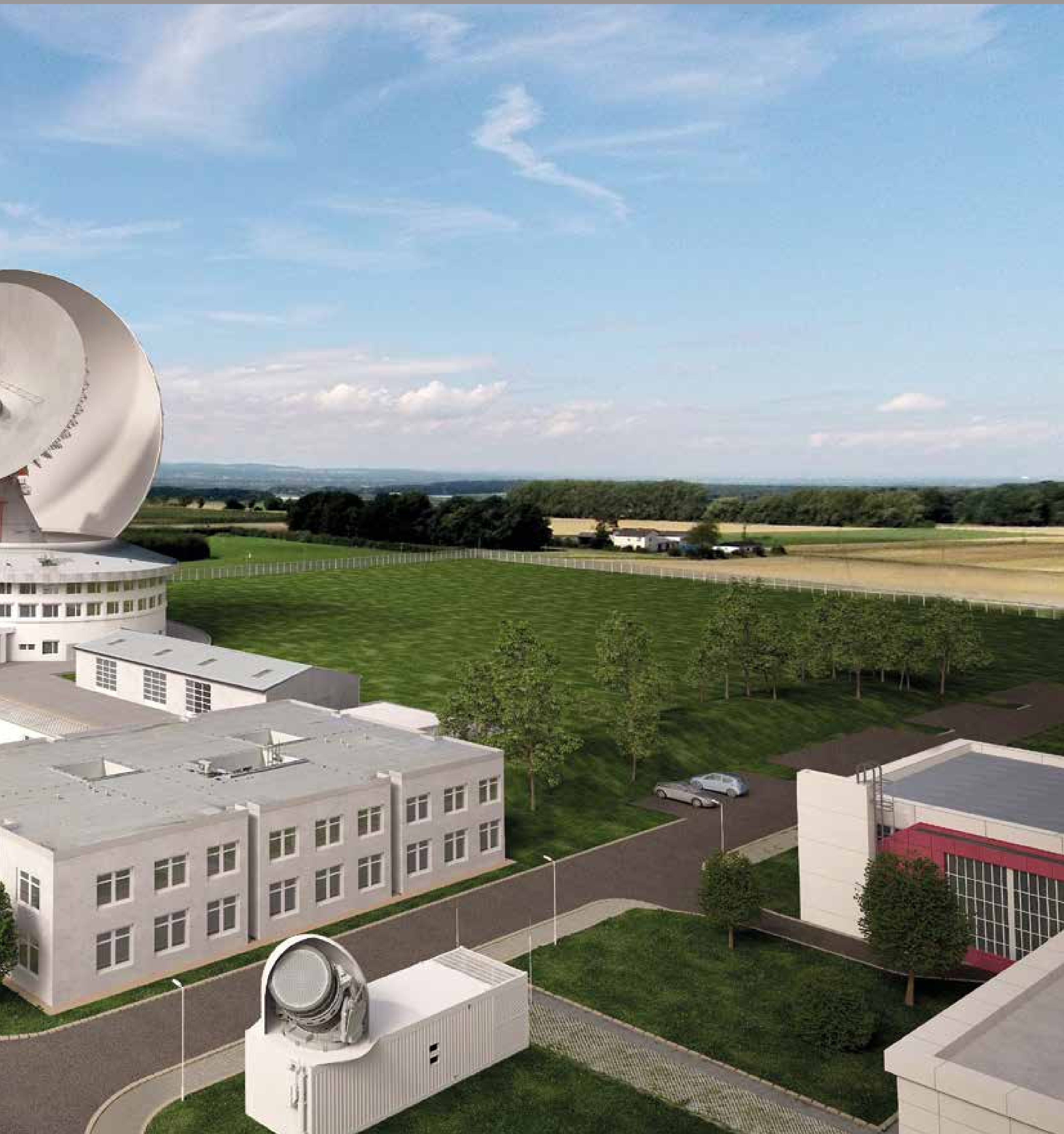
FRAUNHOFER FHR IN PROFIL

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.

Artwork of Fraunhofer FHR buildings with open TIRA and GESTRA antenna.



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 resolutions of up to 3.75 mm. The range of application of these devices reaches from systems for reconnaissance, surveillance, and protection to real-time capable sensors for traffic and navigation all the way to quality assurance and non-destructive testing. Fraunhofer FHR's systems are characterized by reliability and robustness: Radar and millimeter wave sensors are suitable for demanding tasks, even under rough environmental conditions. They work at high temperatures, with vibrations, or under zero visibility conditions caused by smoke, vapor, or fog. Thus, radar and the related high frequency systems are also key technologies for defense and security. In this area, the institute has been supporting the German Federal Ministry of Defense (BMVg) since the institute was founded in 1957.

On one hand, the processes and systems developed at Fraunhofer FHR are used for research of new technologies and designs. On the other hand, together with companies, authorities, and other public entities, the institute develops prototypes to overcome 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 technologies range from the traditional waveguide base to highly integrated silicon-germanium chips with frequencies of up to 300 GHz.

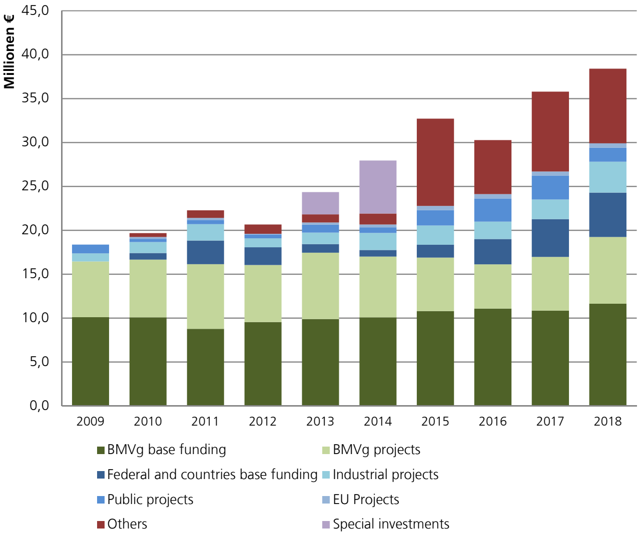
The ability to carry out non-contact measurements and the penetration of materials open up a range of possibilities for the localization of objects and people. Thanks to the advances in miniaturization and digitalization, the high frequency sensors of Fraunhofer FHR with their special capacities are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

Staff and Budget Development

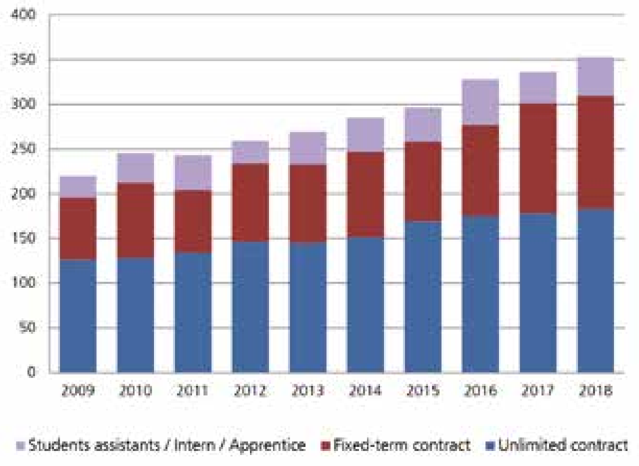
The institute's budget comes from several sources of financing: The basic financing from the German Federal Ministry of Defence (BMVg), the project financing through funds from the defense budget and the income from the contract research area (Vfa), which in turn can be subdivided into economic revenues, public revenues, EU revenues, others, and the basic financing by the German Federal Ministry of Education and Research (BMBF). In 2018, in its defense and civil segments, Fraunhofer FHR generated total revenues of 38.4 million euros.

At the end of the year 2018, Fraunhofer FHR had a total of 383 employees, a 5.0 % increase compared to the previous year. 183 are permanent employees and 126 temporary employees. The 44 remaining employees are students and apprentices.

Budget development 2009 - 2018



Staff development 2009 - 2018



1 Photo of Fraunhofer FHR buildings and the space observation radar TIRA in Wachtberg.

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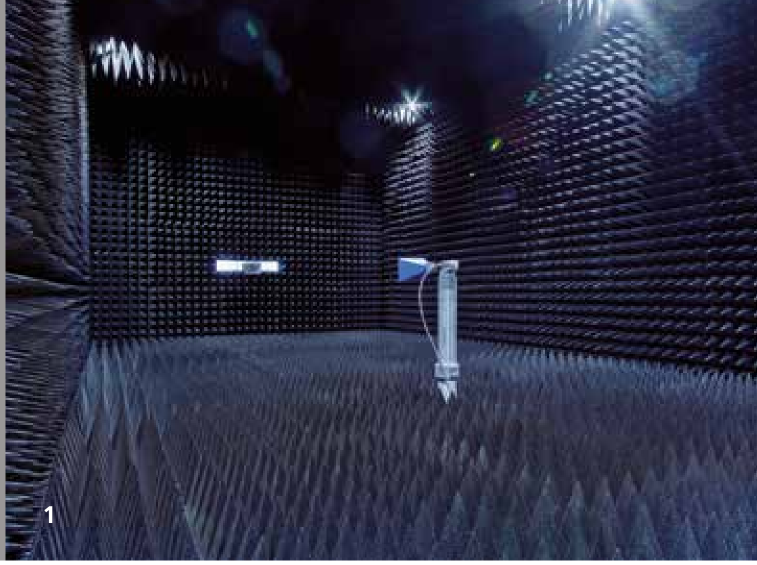

FMD@FHR: YOUR ACCESS TO CUTTING-EDGE TECHNOLOGY PARKS

As part of the »Research Fab Microelectronics Germany« (FMD), Fraunhofer FHR invested about 6 million euros in cutting-edge technology in 2018. The funds were used for the development of competencies and activities around the innovation topic of microelectronics.

Within the scope of the FMD, the Federal Ministry of Research supports 13 research institutes with funding totaling 350 million euros. More than 2,000 scientists in the FMD make up the largest cross-site research and development association for micro and nanoelectronics in Europe.

This new type of cooperation combines the advantages of two strong decentralized research organizations – the Fraunhofer-Gesellschaft and the Leibniz Association – with the synergies of a centralized organization to form the world's most powerful provider for applied research, development, and innovation in the micro and nanoelectronics area. Thanks to the close links and the coherent approach, the FMD is able to provide wider and easier access to the next generation of technology, not only for large-scale industrial clients but also – and especially – for small and medium-sized business as well as start-ups.

To organize these competencies and resources, a cross-institute One-Stop-Shop was created in Berlin in 2018 for all inquiries and topics involving the FMD. But a lot has happened in 2018 at Fraunhofer FHR in Wachtberg as well, thanks to the FMD.

Rapid Prototyping & Additive Manufacturing

Providing the first clear demonstrators, directly producing and testing innovative component concepts, simplified spare parts supply, or replacing defective housing components: This is only a handful of examples where additive manufacturing is used these days.

For this reason, in 2018, Fraunhofer FHR expanded its additive manufacturing capacities with 3D printers. The application possibilities are manifold for the millimeter wave technology, because additively manufactured components allow a fast, economical adaptation of the developed radar systems. In particular, new materials often lack information about the material properties in the millimeter-wave range, so new materials are first characterized on the company's own measuring stations over a wide frequency range. After that, it is possible to completely produce, for example high frequency antennas, with a 3D printer. This procedure not only saves time and costs, the systems are also lighter thanks to the plastic parts – an important factor, especially for airborne systems. By mixing different materials or the structuring in the sub-wavelength range, homogenous and inhomogeneous materials with different refractive indices can be produced to create new types of antennas with more degrees of freedom.

In order to be able to better pursue these approaches in the best possible way, in addition to the further characterization of various printing materials, the purchase of three special printers is also planned for 2019. In addition to an extraordinarily large installation size of up to one cubic meter, the

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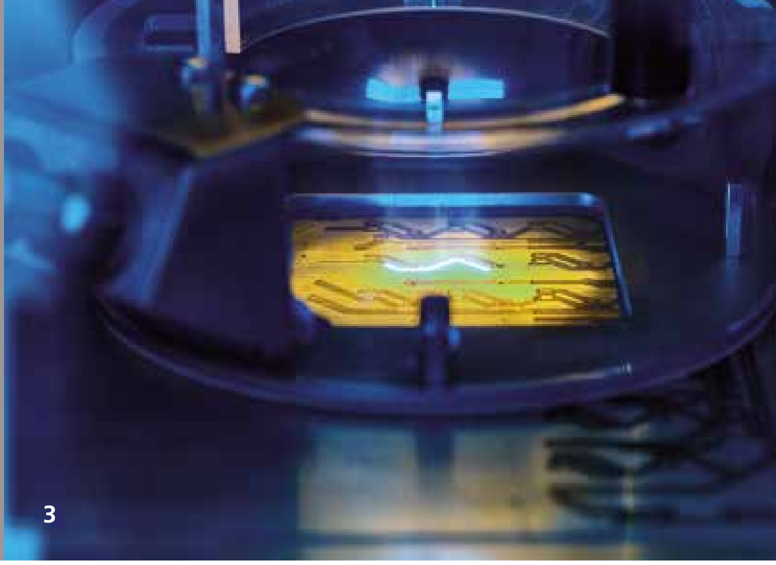

3

institute is planning selective laser sintering (SLS), 3D printing with plastic and metal powders, and the testing of a 5-axis metal printer.

Construction Technology & Heterointegration

In the heterointegration area, the FMD association produces components in the millimeter wave and terahertz range. By producing the printed circuit boards required for the radar systems in-house, it is possible to respond to special requirements immediately and to save time and costs in the long run. That is why different construction technology devices were acquired within the scope of the FMD, including the laser milling machine shown in figure 3. The laser operates at a wavelength of 355 nm and allows for the manufacturing of structures with a resolution of up to 20 µm. Additional acquisitions are planned for 2019.

Measuring Laboratory for High Frequency Radar Systems

The ability to assess the capacities of antennas, subsystems, and complete prototypes requires an anechoic chamber with a suitable measuring system consisting of network analyzers and the fitting high frequency modules. Within the scope of the FMD, Fraunhofer FHR invested in a measuring laboratory in the millimeter wave range. Figure 1 shows the interior view of the anechoic chamber with a measurement setup for antenna characterization. The transmitter is located behind the feedthroughs to the anechoic chamber. The receiver is positioned at a distance of up to 6 m and can be rotated at a 360° angle range with increments of less than 0.5°. For a quasi-monostatic measurement, instead of the receiver, an object could be mounted for which the radar cross section (RCS) is to be determined. In addition, radar systems can also be tested and characterized using reference objects.

The anechoic chamber allows for measurements of frequencies above 20 GHz under controlled environmental conditions. Interferences to the propagation of electromagnetic waves are minimized, thus allowing for the testing and evaluation of components.

1 *Interior view of the anechoic chamber, configured for the measurement of an antenna.*

2 *3D printed antennas (on the left) offer the same performance with less weight and lower production costs than conventional Teflon antennas (center & right).*

3 *Laser milling machine LPKF ProtoLaser U4 processing a printed circuit board.*

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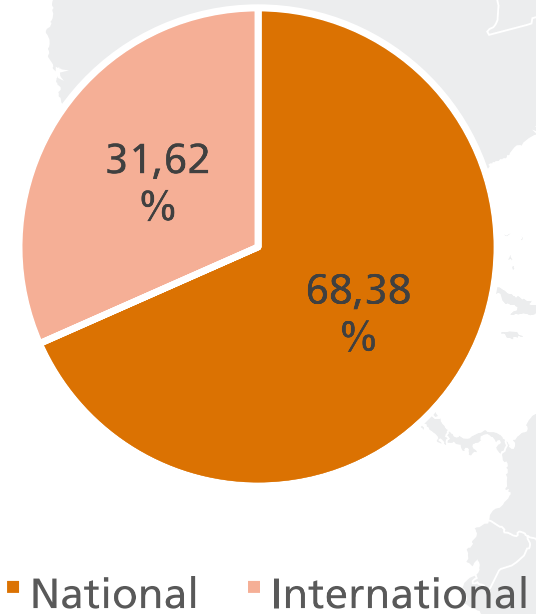
FRAUNHOFER FHR IN THE MEDIA

Countries



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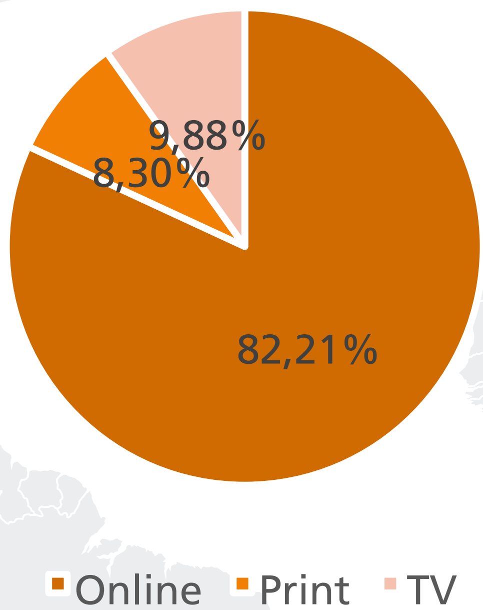
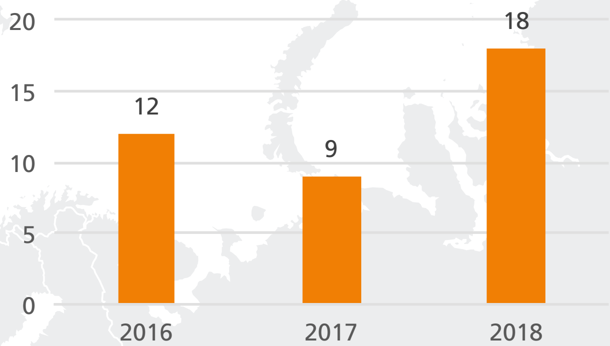
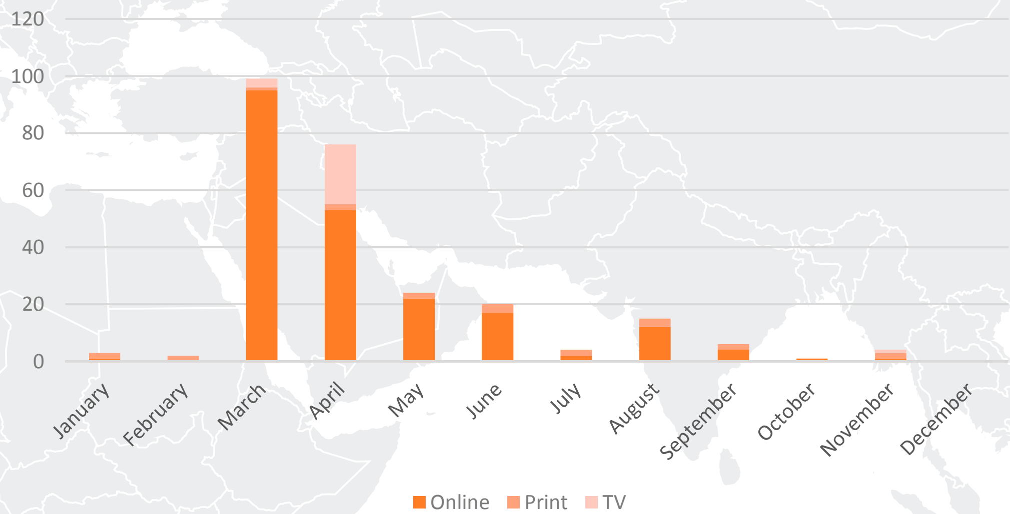


Press Information of Fraunhofer FHR



Reports with Fraunhofer FHR in 2018



On Easter 2018, the Chinese space station Tiangong-1 entered the earth's atmosphere and crashed. Accompaniment by the Fraunhofer FHR with unique radar images was disseminated worldwide in the leading media.

OVERVIEW

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Federal Ministry of Defence (BMVg)
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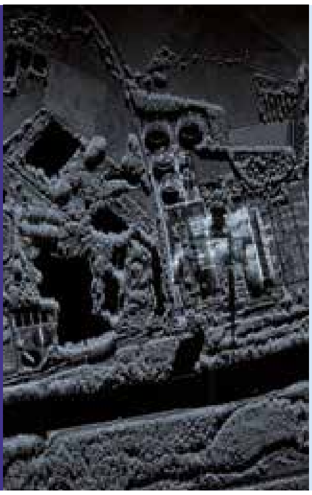
Winfried Wetjen
OHB-System AG
Bremen

Attendees of the Advisory Board meeting on June 29., 2018, on the institute's premises in Wachtberg: Prof. Loffeld, Dr. Krag, Mr. Hommel, Mr. Pappert, Prof. Martini (Director of Fraunhofer FKIE), Mr. Neppig, Prof. Knott (Director of Fraunhofer FHR), Dr. Weber (Fraunhofer Head Office), Dr. Roth (Fraunhofer Head Office), Prof. Rohling, Dr. Elsbacher, Prof. Heberling (Director of Fraunhofer FHR).

BUSINESS UNITS



DEFENSE

Smart, modular, multi-modal and compact – these are the special demands placed on future radar systems that have formed the focus of research at Fraunhofer FHR for many years already. In addition to the surveillance and reconnaissance techniques, the scientists also investigate innovative concepts for camouflaging and hardening internal radar systems as well as for jamming or deceiving enemy systems. With its extensive know-how, Fraunhofer FHR covers the entire spectrum of high frequency and radar techniques for defense purposes.

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SPACE

Fraunhofer FHR is one of the leading research institutes in the area of space observation. With TIRA, the institute has a practically unique system for space surveillance. To enable uninterrupted space surveillance, Fraunhofer FHR is also currently developing GESTRA on behalf of the aerospace management of the German Aerospace Center (DLR-Raumfahrtmanagement). In the area of radar-based space reconnaissance, Fraunhofer FHR combines the entire system chain under one roof and can supply its partners with everything they require from a single source.

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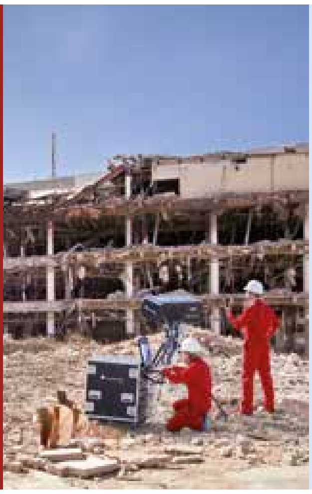

SECURITY

Research into forward-looking security solutions has always been a key issue at Fraunhofer FHR. The institute focuses on the development of compact sensor technologies which can provide emergency personnel with detailed images and information relating to the respective situation – in real time and in all weather conditions. Radar systems are therefore ideal for applications in accident scenes that are difficult to access as well as in the area of prevention for the detection of explosive devices, weapons and unauthorized objects (e.g. drones).

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TRAFFIC

Radar offers numerous possibilities for applications in the air, at sea or in road traffic. Fraunhofer FHR investigates ways of leveraging this potential in various projects. The institute's partners have access to an extensive service portfolio: from technology consulting to design, construction and prototype development. Work at the institute focuses on finding efficient and prompt solutions to problems that arise during the development of a new product.

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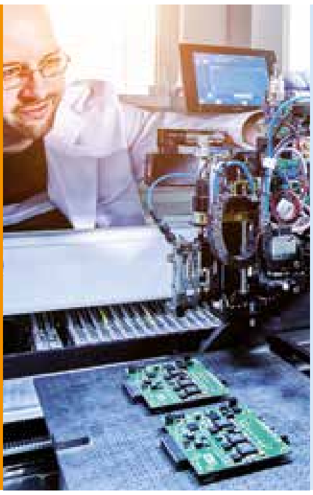

PRODUCTION

Innovative, customized sensors for production and industry have been a focal point at Fraunhofer FHR for many years already. The institute conducts research on compact sensors for quality control in real time. Apart from in-line capability and reliability, the price also plays an essential role in the development phase. The activities in the business unit Production aim to make an important contribution to the improved acquisition of production parameters using state-of-the-art technology with the ultimate view of creating further competitive advantages for its project partners.

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HUMAN AND ENVIRONMENT

Thanks to its precision combined with non-contact and penetration functionality, radar can open up completely new application possibilities. High-resolution imaging is also possible from large distances. The research activities of the institute also investigate application fields in the areas of health and medical technology as well as environmental- and geomonitoring.

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MULTIFUNCTIONAL COHERENT RADAR NETWORKS

By opening up higher frequency ranges, imaging radar systems can be miniaturized and built in a cost-efficient manner. The cooperative operation of several of these systems in a network leads to improved reconnaissance capabilities, reduced vulnerability, and additional applications.

In the last decades, we have seen the development of imaging radar sensors capable of generating high-resolution images of a scene, based on the synthetic aperture radar (SAR) principle. Depending on the application, these radar sensors are either airborne or space-based and operate with wavelengths in the range of a few centimeters, for example with 3 cm in the X-band. These types of sensors tend to be highly complex, high-power, and high-volume. Therefore, operating them requires the use of a larger carrier. Thanks to the development of the newest components, SAR systems can now be set up for higher frequencies as well. And limiting oneself to the basic capabilities makes it possible to create cost-efficient mini sensors, allowing for the operation of sensors in the W-band working in the wavelength of around 3.2 mm on standard drones, for example.

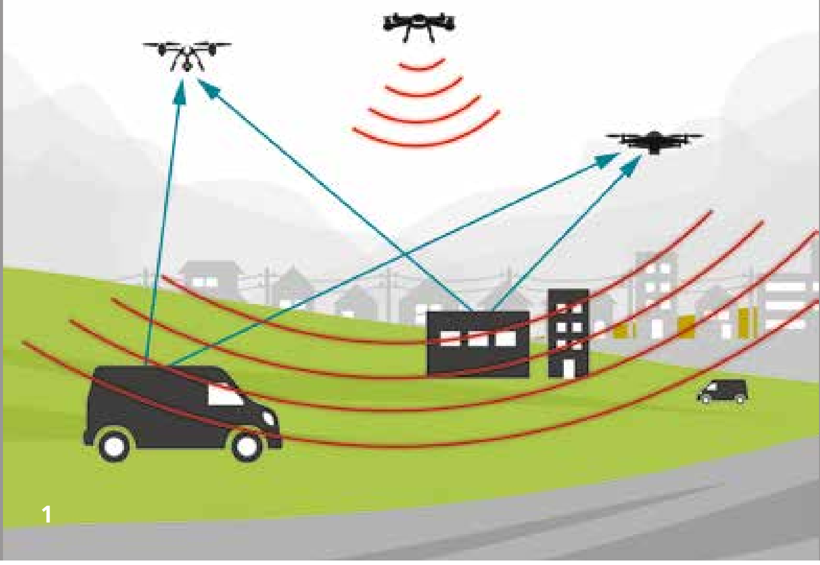
Since the setup and operation of a conventional system involves significant expense, such a system is usually run purely monostatically on a stand-alone basis. In contrast, the cost-efficient combination of a W-band sensor and a standard drone provides for the possibility of improving performance by using several of these types of subsystems. This leads to a variety of advantages:

1. The cooperative operation of different subsystems allows for bi and multistatic images providing a gain on information as different aspects of the imaged scene are revealed.
2. The inherent distribution of the overall capability among multiple drones improves the robustness and reduces the vulnerability.
3. It offers easy scalability, where the number of sensors and drones used, for example, the enlightened surface, the frequency of observations or the diversity of the directions of observation can be adapted to specific needs. Thus, the coherent radar network can be used for a wide range of different reconnaissance tasks.

Challenges of the Wireless Hardware Synchronization for Millimeter Wave UAV SAR Sensors

An essential aspect of the hardware development for a multi-coherent radar network carried on drones is the synchronization of the transmission systems in the millimeter wave range. To keep the entire system as small and light as possible, a frequency range of approximately 94 GHz is chosen. For energy efficiency purposes, a frequency modulated signal form is chosen. Both are necessary secondary conditions for drone operation. In the process, the low wavelength creates special challenges for the techniques as different offset radar sensors have to be synchronized in a phase-locked manner so that the processing ensures the high-resolution SAR operation.

To avoid high scanning rates of the IF, a number of different synchronization processes must already be performed at the hardware level in real time. This ensures that both the direct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signal received by the secondary receiver as well as the indirect signal reflected by the measured object fall into the IF range to be sampled there. The synchronization has to be wireless, but also phase-stable in the millimeter range. This requires the development of new techniques.

Challenges of the Signal Processing for Distributed Imaging Radar Sensors in the Millimeter Wave Range

Backprojection in the time domain presents itself to reconstruct the image when there are different flight constellations. Due to the use of drones as a sensor carrier in conjunction with lightweight and cost-effective position and attitude determination systems, unknown radar signal propagation times remain and are compensated for by the use of appropriate autofocusing techniques. In addition, there is also an unknown propagation time error in the direct signal, which serves as the basis for the synchronization on the hardware level. This error has to be determined and corrected as an additional parameter within the scope of the auto-focusing process.

Further issues have to be addressed for operational use. Since the use of time domain processes involves high computing capacities, tested processes have to be parallelized and fast processes have to be implemented in order to obtain acceptable processing times.

1 *Leightweight airborne radar sensors co-operating in a network provide advantages for reconnaissance. Synchronization is carried out with the aid of direct signals.*

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DRONE NAVIGATION BASED ON RADAR IMAGES

The reliability on the existing navigation systems is essential for the navigation of reconnaissance drones. If the global navigation satellite system is disturbed, the inertial navigation system can be supported by a process in real time processed radar images for radar image based navigation and the accuracy can be improved.

As there are often local disturbances in global satellite navigation systems in crisis areas, these systems cannot be used for navigation. The navigation of aircraft is only possible based on the data of the inertial navigation system in poor visibility conditions. This system consists of ring laser gyroscopes and acceleration sensors. The position is calculated based on the integration of the sensor information. Even though these systems are highly accurate nowadays, there is always a residual error that adds up to a more significant position deviation over time.

Military reconnaissance drones are frequently equipped with an all-weather imaging radar system used primarily for reconnaissance. Due to the computing power currently available, radar images with a reduced resolution can already be processed in real-time on board the drone and compared to digital map data. When prominent objects such as road crossings, rivers, or lakes are detected, they can be matched to the map data to determine the exact position of fixed points. If there are several of these fixed points, the exact position of the drone can be calculated based on the known geometry made up of distance measurements and angles of vision.

The Kalman filtering of the navigation data and the supporting point of the position generated by matching the radar images with the map data allow for correction and support of the drone's navigation system. This prevents the position from deviating over time.

Even though this process cannot reach the accuracy of satellite navigation systems, this navigation method provides sufficient precision to carry out a mission in a region with a disturbed satellite navigation system. The accuracy of the navigation depends on the precision of the real-time radar image generation as well as the number, position, and position accuracy of the fixed points found.

The basis for radar-based navigation is an imaging radar sensor with analyses in real-time. At Fraunhofer FHR, the radar system MIRANDA-35 has been used for this. It runs with a center frequency of 35 GHz and a bandwidth of up to 1500 MHz. It also has a data transmission path to the ground station through which the radar is controlled and the images of the online processor are transferred.

To test the method for radar image based navigation, two suitable data sets were recorded on a flight route of approximately 100 km each along with the associated raw navigation data. With these data sets further processing was first done offline to thoroughly test the methods and routines while ensuring their repeatability. First, the company IGI, the manufacturer of the navigation system, subtracted the GPS signal from the raw navigation data. Thus, a navigation data set was generated like one that would have been created in case of a failure of

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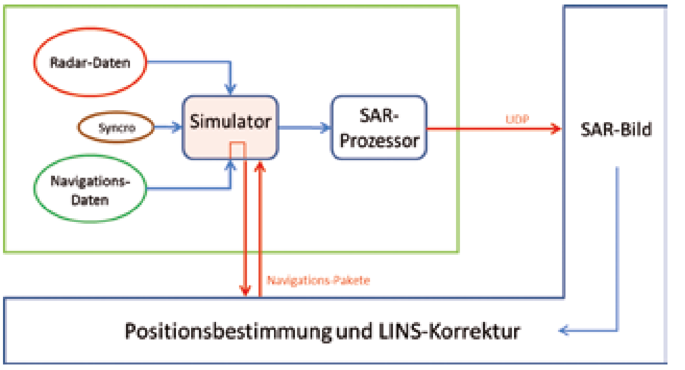

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the satellite navigation system. With this, two navigation data sets were available for each SAR data set: on one hand, the original data set from the existing satellite navigation system and, on the other hand, the adapted data set without a usable GPS signal.

Then, the adapted navigation data sets were fed into the SAR processor together with the raw radar data set and processed. The generated radar images were transferred to a computer of the project partner Airbus, where they were matched with the map data and the position was determined. The results of this determination of position were forwarded to a Kalman filter together with the data of the navigation system. The Kalman filter then corrects the navigation data and in turn feeds the correction values into the SAR processor.

It was demonstrated that it is possible to support the on-board navigation system with radar images. Even though the accuracy of a satellite navigation system cannot be reached, a continuous deviation of the position is effectively prevented. The achievable position accuracy is more than sufficient for a smooth mission and can be ensured for the entire duration of the mission.

1 *MIRANDA-35 radar sensor, mounted under the wing of the microlite aircraft DELPHIN.*

2 *Detail of a quicklook radar image of a measurement flight with a reduced resolution of approx. 2.7 meters.*

3 *Schematic diagram of the used offline data processing.*

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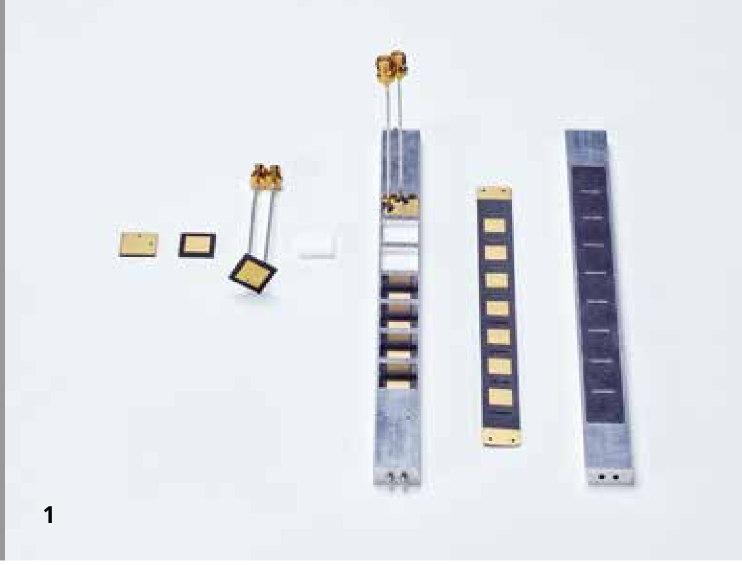

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EXAMINATION OF THE SCAN-ANGLE DEPENDENT ACTIVE IMPEDANCE OF CONFORM APERTURES

The curvature of an array antenna's aperture plane has a fundamental effect on relevant parameters such as the measure of the mutual coupling of the emitting elements and, with this, on the active steering impedance of each individual radiator. The ability to efficiently predict these effects numerically is of great interest for practical applications.

Coupling in Broadband Array Antennas

The numeric examination of the radiation properties of electrically large array antennas is highly CPU-intense. For time reasons, idealized radiators are frequently modelled with electromagnetic properties that are independent of their environment. It is comparatively easy to specify the far field of arrays of such idealized radiators. In practice, however, it has been shown that this very simplified approach does not provide sufficiently accurate predictions of an array antenna's capacity. Real radiators couple significantly by means of, among others, waves propagating on the carrying structure, of free space radiation, or of imperfect feeding networks. These interferences produce noticeable deviations between the ideal behavior and the measurements. Depending on the configuration of the array, these deviations reach from a moderate deterioration of the capacity up to the total loss of the emission capacity at specific steering angles (co-called blind spots). This last case occurs because of a significant missmatch to the active impedance of the radiators.

In addition, for future systems, it will probably no longer be sufficient to consider the coupling for one function within an array (narrow band). It is becoming apparent that the coupling has to be looked at between multiple arrays or within an array via multiple modes (broadband) because of the increasing number of array antennas on platforms.

Development of Tailored Modelling Tools

The modelling of the coupling of the radiators is by far the most time-consuming step in the numeric design of electrically large array antennas. For large planar structures with regularly arranged radiators, except for the edge elements, the coupling can be examined comparatively quickly with a good accuracy using so-called Floquet modes. In the process, the time savings are a result of the assumption of the periodicity of the fields. Thus, only a comparatively compact unit cell has to be analyzed, instead of the entire structure.

If, in contrast, an electrically large array antenna has to be designed with a curvature, for instance because it has to be platform-integrated, there are no suitable commercial modelling tools available at present. That is why, at Fraunhofer FHR, special numeric methods have been tested with the goal of efficiently predicting the coupling of the radiators, taking into consideration the curvature.

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Metrological Examinations

A broadband antenna demonstrator was designed in 2018 to test the methods developed. The demonstrator is designed in a modular format for the X-band. Individual linear array modules are used as basic elements. These consist of so-called »stacked patch antennas« (figure 1). By means of »3D printed« molded parts (figure 2), a set of linear array modules can be put together under laboratory conditions for apertures with different radii of curvature (figure 3). In addition to circular cylindrical shapes, location-dependent curvatures can also be implemented. Since it is expected that the occurrence of coupling effects is polarization-dependent, all radiators can be stimulated in two polarization modes that are orthogonal to each other. To be able to specifically observe the creation of interferences such as blind spots and grating lobes (significant radiation emittance into unwanted solid angles), the radiator pattern can be varied using printed blind modules. First measurements on isolated radiators show a high level of consistency with the simulation.

Outlook

In the near future, the coupling will be measured for typical curvature profiles. The accuracy of the developed numeric methods will be checked. If the coupling is captured with sufficient accuracy, countermeasures to avoid the reduction of the coupling can be modelled systematically and tested experimentally. Known approaches are, for example, decoupling networks integrated into the feeding networks or the use of purpose-built covers that can reduce the reactive storing of the field energy directly in front of the aperture for blind spots (so-called wide-angle impedance matching structures, WAIM in short). Fraunhofer FHR is planning on designing such WAIMs for typically occurring curvature profiles within the scope of the EDA project METALESA II, which is set to start in 2019, and to test them experimentally using the demonstrator that has already been created.

1 *Radiator module consisting of seven broadband patch antennas (dual polarization).*

2 *Additively manufactured module with different radii of curvature.*

3 *Far field measurements in the antenna measuring chamber (here: curvature radius of 5 wavelengths).*

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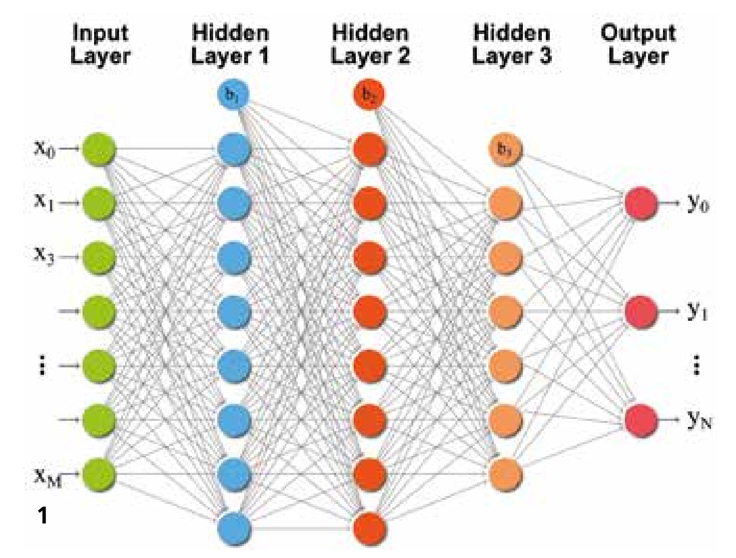


ROBUST DETECTION STRATEGIES WITH MACHINE LEARNING AND COMPRESSIVE SENSING

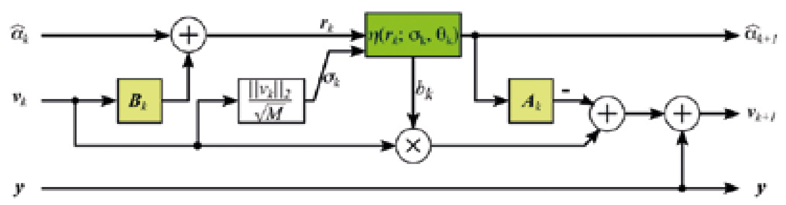
The detection of targets in radar signals is a fundamental process. In areas where huge volumes of data are available to train neural networks (NN), machine learning (ML) has been able to achieve tremendous success, for instance in pattern, image, and speech recognition. The combination of compressive sensing (CS) and ML can solve the problem of missing data volumes, making these methods applicable in this field as well.

The main task of radar systems is to detect moving objects and, if possible, to determine the associated parameters, such as distance and speed. Conditioned by the selected frequency range of the systems and their active emission of coded signals, this capacity is independent of weather influences and the times of the day. Interfering signals such as multiple reflections, noise, or even explicit interference attempts dramatically complicate the detection of weak targets. For moving objects, there is an additional challenge, as the estimation of the parameters is made very difficult by the non-linear movement in relation to the radar system.

In the past years, one research focus was the improvement of the detection using additional external information. This information was used to enrich the actual measurement with additional knowledge to possibly also complement the measurement with information that is not measured, for instance the information that there are only a few moving objects in the observation space. This knowledge is the basis of the »sparse signal reconstruction« or also the »compressive sensing« theory. Fraunhofer FHR already recognized this advantage quite some time ago and thus created the International Workshop on Compressed Sensing applied to Radar, Multimodal Sensing, and Imaging (CoSeRa) in 2012 and intensely supported the workshop in the following years in a similar manner. In 2018, the fifth CoSeRa workshop was held in cooperation with the University of Siegen.

A known disadvantage of the CS methods compared to the classical methods is the high computing power required to reconstruct the observed scene from the measurement data before further signal processing steps can occur. In contrast to CS, classical methods, which filter the measurement data in contrast to CS in such a way that only moving targets remain.

Parallel to CS, the machine/deep learning (ML/DL) research area has led to a renaissance of neural networks in the past years, with considerable success in many commercial applications such as automatic face recognition, speech recognition, machine translation, driverless cars, and robotics. Important components for the success of ML/DL methods are, on one hand, the availability of large volumes of data necessary to train and condition the complex neural networks and, on the other hand, the further development of computing power as well as the current capacity to create non-linear models and adapt them to the existing data. When the conditioned neural networks are available, the ML/DL methods have the potential



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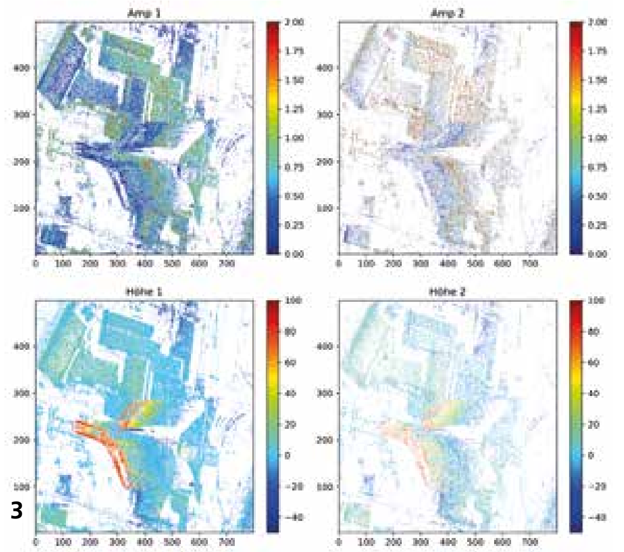

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to provide computationally efficient approaches to improve the target detection, tracking, and classification in radar with an improved resolution.

An active field of research in this context is the integration of compressive sensing and machine learning for radar applications, thus combining the advantages of both methods. For example, iterations of many CS algorithms for the restoration of sparse signals have the structure of neural network layers. Therefore, numerically efficient ML models such as deep neural networks can be used to replace the computationally intensive iterations with fixed depth feedforward networks derived from training data. Furthermore, the learning process allows for the extraction of better dictionaries / transfer functions for the presentation of the observed scene based on the training data. CS-based generative models of targets and interfering signals can be used to create extensive training sets, which are necessary for the ML/DL algorithms. Thus, gaps in the measurement data can be closed by online predictions from a »compressed« database to improve the generalization. This CS-supported training strategy will significantly expand the range of applications in which ML/DL can be used successfully as the availability of large radar data sets is not always guaranteed in the military field.

1 *Typical neural network topology for the detection of structures.*

2 *The k plane of a vector approximate message passing (VAMP) networks which allows for the reproduction of iterative CS algorithms.*

3 *For interferometric SAR images of urban areas, there are several point scatterers in a distance azimuth cell. These can be detected and presented individually with the combined ML/CS method. The image shows the first two detections with their amplitudes and heights.*

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INTELLIGENT ELECTRONIC COUNTERMEA-SURES (ECM) AGAINST MODERN RADAR SYSTEMS

The initiation of suitable countermeasures against enemy radar presents a major challenge for both symmetric as well as asymmetric conflicts. Over decades, Fraunhofer FHR has developed an enormous expertise in the area of electronic warfare (EW), especially in electronic countermeasures (ECM).

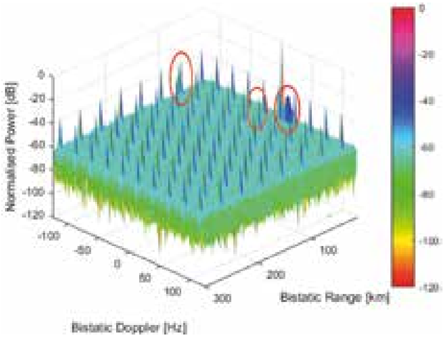
The research and development of »unconventional« radars is progressing at an increasing pace and with this, their use in future threat scenarios is becoming more and more likely. A »conventional« radar features specific technical properties for which there is still no widespread use at present. Besides monostatic, bistatic, and multistatic radars, this includes passive, adaptive-active, and cognitive systems as well as low power radars (LPR), radars with arbitrary or randomizing waveforms (noise radars), and networks of radars.

The scientists at Fraunhofer FHR have outstanding expertise in the development of unconventional radars as well as the corresponding radars for suitable electronic reconnaissance (ESM) and countermeasures (ECM). True to the philosophy »create to learn«, they develop radars such as noise radars, passive radars that use third-party illuminators, static and moving multistatic radars, LPR, multifunctional RF systems, and radar networks. In addition, they possess extensive knowledge of the complexity of intelligent ECM, while always turning their sights to topics relevant for the future and maintaining a close cooperation with national and NATO allies in order to be able to efficiently face complex threat scenarios in the future. The national and international relevance of the research work in the areas of ECM and unconventional radars are demonstrated within the scope of numerous research activities. Representatives of Fraunhofer FHR lead joint NATO and EU research groups concerning the topics of ECM, passive radar on moving platforms, and synchronization of radar networks, among others.

Below, we will present a variety of examples for intelligent ECM against unconventional radars.

ECM Against Passive Radar

Passive radar uses available third-party illuminators such as radio or satellites for target detection, i.e. the transmitter and the receiver are dislocated. Passive radar is tremendously important in the military sector and will likely be a central element in the defense infrastructure of the future. That is why research into suitable ECM is of essential importance. This presents a major challenge, as the position of the receiver is generally not known, and therefore the jamming signal cannot be directed to a specific direction. In cooperation with partners, researchers of Fraunhofer FHR have developed techniques to intelligently jam and deceive passive radars largely independent of their exact position. For example, a radar's detection capabilities can be prevented completely by having the ECM system emit a low power signal (see figure 3). In addition, many passive radars use OFDM-based (orthogonal



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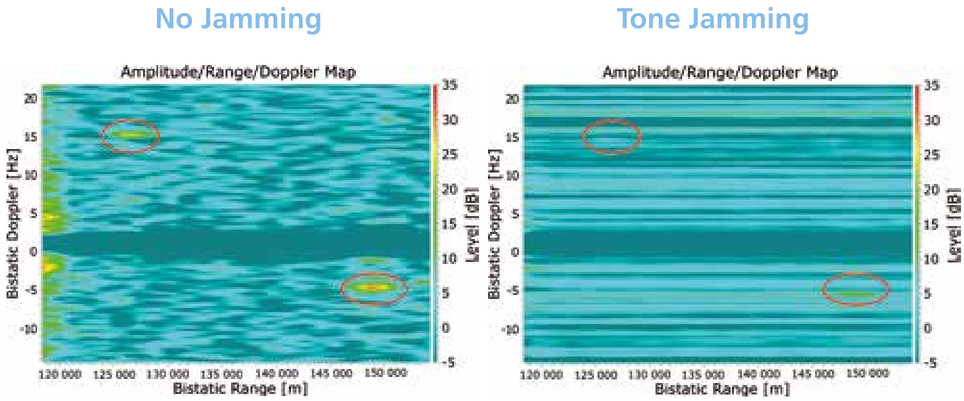

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frequency division multiplex) waveforms. With a differentiated manipulation of the pilot and carrier signals, the target detection can be concealed or a false target can be generated. Figure 2 shows an example for the manipulation of the OFDM carrier signal.

ECM Against Low Probability of Intercept (LPI) Radar

To prevent the detection of one's own platforms by radars with a high time-bandwidth-product (e.g. LPI radars), noise jammers are often ineffective. An optimization can be achieved by utilizing the matched filter gain. For this, a parameter estimation of the radar pulse is performed first by suitable ESM systems. New methods from the »machine learning« field can be used to estimate the signal parameters. For example, to determine the modulation, the time-frequency-representation (e.g. auto ambiguity function) of the receive signal can be calculated. This is then classified by a »convolutional neural network«. The signal parameters obtained from this can be used to interfere with the radar by generating numerous synthetic false targets.

Sophisticated broadband receivers have been developed at FHR to register different threat radars. Figure 1 shows a hardware example.

ECM Against Cognitive Radars

As digital technology progresses, the application of new signal forms or techniques will lead to radar threats changing at an increasingly fast rate in the future. This means that suitable countermeasures will have to be adapted in comparable time frames to ensure their effective applicability. Future systems for electronic warfare will be based on reconfigurable hardware and software so that new radar threats can be detected and characterized during the application. Then effective countermeasures are derived from this with as short of a reaction time as possible. For this purpose, the learning and adaptation process of the now flexible threat library will receive feedback to assess the effectiveness of the measure and to directly adapt and optimize the interference technique to be applied.

1 *A broadband »electronic support measure« receiver.*
2 *Suppression of target detections and generation of deception targets for passive radars by manipulating the OFDM carrier signal.*
3 *Complication of the target detection with passive radars using low power interference signals.*

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SPACE SURVEILLANCE WITH GESTRA

The integration work and the testing of the individual subsystems are in full swing. In 2019, GESTRA (German Experimental Space Surveillance and Tracking Radar) will be transported to its final installation site in Koblenz, Germany, where it will be tested and calibrated as a complete system. In 2020, the system is to be handed over to the German Space Situational Awareness Center (GSSAC) in Uedem. On one hand, the GSSAC will then have a high-power radar sensor for space surveillance at its disposal. On the other hand, GESTRA promises to also provide other research institutes in Germany with valuable data for scientific use.

Integration and Monitoring of the Radar Infrastructure

Because of the high transmitting power, the partially mobile system will have a quasi-monostatic design. This means that the transmission and receiver systems will each be integrated into separate containers with dimensions of 18 x 4 x 4 m3. The integration of the subsystems into the containers was carried out in the order determined by the spatial conditions. First, the energy distribution cabinet was installed with all of its safety relays and high-current switches and then the heavy-duty scissors lift, the oil-free compressor, and the air conditioning system with its ventilation and suction pipework. This was followed by the installation of the energy supply units for the transmitting and receiving antennas and their integration into the control system. The installation of the cooling system into both containers was a highly complex integration process. The liquid cooling systems of the transmitting and the receiving unit consists of a primary cooling circuit with complex cold-water preparation and air back cooling as well as a secondary cooling circuit with a coordinated pump system to cool the antenna, the transmitting transformer, the radar processor, and the air conditioning. After all dedicated cooling and dehumidification units were integrated, the piping for these subsystems was installed. It was only possible to guarantee adequate spatial volume for the subsequent integration of the cable lines on the container ceilings for the subsystems' electrical power supply thanks to the detailed 3D system modelling of all devices and pipework. This multi-level line installation also ensures that the arrangement of the water and compressed air hoses is suitable for the transport.

The integration of the radar processor in the 3-rack format with a power loss of 45 kW and the built-in fire extinguishing possibility allows for the early analysis of the computing capacity to test the signal processing algorithms. After all of the mentioned subsystems were connected electrically, the next step was to implement and test all monitoring and sensor systems in these devices. Especially noteworthy here is the reliable air conditioning and dehumidification of the operating rooms to prevent condensate effects at low temperatures. The current constant monitoring of all operating states and environmental parameters of all integrated devices by means of an optimized monitoring program provides insights into the radar infrastructure's implemented product reliability. The antenna front end with the positioner will be installed in both containers in March 2019.

Currently, the integration work to set up the receiving model and then the receiving planks is underway. This will be followed by the equipment of the transmitting plank and the continuous antenna integration with all supply units. It should

be emphasized here that the very complex, 130 cm long backplane circuit boards, which have been developed with a high manufacturing risk for supplying the planks, have been delivered and tested completely, thus being ready for installation.

Signal Processing

In addition to the optimization of the radar's physical properties, GESTRA's detection capabilities are to be improved primarily by the signal integration based on as many pulses as possible. For this purpose, a model of the target signal will be parametrized for all relevant characterization values, before it undergoes an adapted signal processing in the value ranges to be expected for typical target objects in the low Earth orbit. The tracklet information will be derived from the subsequent threshold decision and the initiation of the orbit tracking of the object. This tracklet information will then be synthesized to a complete track by the Space Situational Awareness Center.

Remote Control of GESTRA

As a rule, GESTRA is designed to be operated remotely by the GSSAC, without on-site personnel. Accordingly, all components have been designed systematically for remote serviceability, including the possibility for a complete restart from a de-energized state. Security is guaranteed for this process: The encrypted end-to-end communication certified by the German Federal Office for Information Security (BSI) provides for tap-proof connections, while the three-network topology as well as the state-of-the-art firewall complete the overall concept.

To get to know the later operating procedures, a GESTRA command and data interface simulator based on the final network protocols was delivered to the future users in 2018 so that they can prepare their mission planning and analysis software parallel with the completion of the system hardware for the operation.

1 *Visualization of the Track-While-Scan mode.*
2 *GESTRA transmission plank equipped with three high-performance transmitter modules.*
3 *View of the GESTRA high-performance transmitter module with a pulse output of >1000 W.*

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EVERY DB COUNTS – IMPROVED DETECTION SENSITIVITY OF PHASED ARRAY RADARS THANKS TO CRYOTECHNOLOGY

With the new, exciting research topic »cryo-cooled receiver systems for phased array antennas« Fraunhofer FHR is leading the way to further improve the sensitivity and, with this, the capabilities of radars. The technical implementation for the lowering of the system noise temperature has great potential for the development of trendsetting space surveillance radars.

After the successful completion of a first research project on behalf of the DLR Space Administration, the work in the field of cryotechnology was intensified in 2018. In the process, technologies were designed to lower the noise temperature of radar receivers. The optimization of the signal-to-noise ratio (SNR) is essential for the detection and cataloging of tiny objects in low Earth orbit (LEO), thus helping to improve the current awareness of the space situation.

Development of a Suitable Measuring Environment

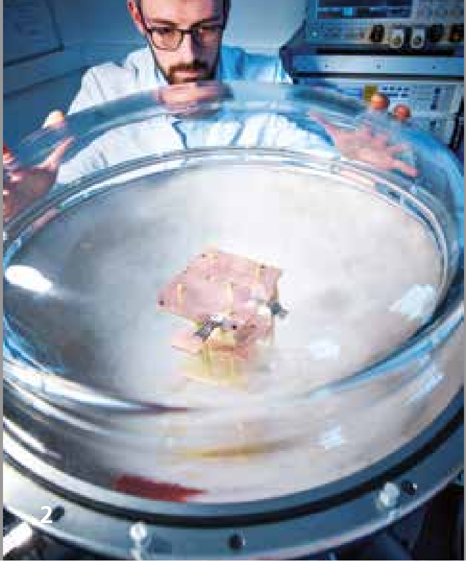
To significantly increase the sensitivity, the receiver has to be cooled down to temperatures as low as -270°C (~4°K). To determine the improvement, the noise temperature has to be measured in a receiving system, and this places special demands on the measuring environment. Thus, evacuated stainless steel vessels (dewar) have been developed that allow for the cooling down to very low temperatures through the vacuum and the thermal shielding of the experimental platforms from the environment.

Currently, a large measuring dewar (height 840 mm, diameter 620 mm) is used for a variety of examinations. The performance characteristics of the used cryo-cooler including all add-on components were measured and a detailed thermal load diagram was created. This is used to determine the necessary number of cryo-coolers for a future scalable phased array system.

At the moment, an additional smaller vacuum vessel (25 x 25 x 10 cm3) is being set up and optimized. Because of the lower mass and the smaller anechoic chamber, this dewar is more flexible in its use, thus offering a platform for smaller and faster low temperature experiments. To reach a temperature of < 20 K on the experimental platform, a two-stage cryo-cooler is used. In the first stage (77 K), the thermal load irradiating from the outside is carried off. In the second stage, the experimental platform is at < 20 K. The gilding of the radiation shields in the first stage provides for an additional reduction of the thermal load, as the thermal radiation is reflected.

Measuring Technology to Determine the Noise Temperature – Heated Load

The correct determination of the noise temperature at < 20 K requires fully developed high frequency measuring technology, as the material and HF properties change significantly at very low temperatures. Furthermore, the heat input of the 290 K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ambient temperature environment (e.g. by HF cables) to the < 20 K experimental platform has to be kept as low as possible. To achieve this, the necessary noise source is brought directly into the environment with T < 20 K. For an optimized measurement of the noise temperature, a so-called »heated load« is developed. This heated load consists of a 50 ohm HF terminating resistor that can be set to different defined temperatures by means of a heating resistor. This method allows for a very precise determination of the noise temperature. The challenge here is that, on one hand, the terminating resistor has to be thermally decoupled from the system so that the component is not also heated up but kept at a temperature in a thermally stable manner. On the other hand, the resistor has to be connected in a thermally sufficient way in order to quickly reach the desired low temperatures.

The First Prototype of a Scalable Individual Receive Channel

To implement a flexible cryogenic phased array radar, the cryo-cooled receive channel is designed for scalability. First, a mechanic support structure is necessary for the first amplifiers. This structure also acts as a radiation shield for the first and the second stage. In the process, the structure has to resist the mechanical stress caused by the cooling while also maintaining the different temperature levels thermally decoupled from each other. A first successful prototype has already been developed and submitted to a variety of tests.

Cryo-suitable HF Windows

To design a future cryo-suitable phased array system so that it is vacuum-tight and can be penetrated by electromagnetic radiation, a suitable radome material has to be found. For the first examination of these HF windows, a special plastic cap in the form of a torispherical head was designed for the large dewar. This HF window makes it possible to build a cryo-cooled receiver where the antenna is cooled as well. First vacuum and stress tests show that the torispherical head offers the necessary stability. The analysis of alternative materials and radome forms as well as HF examinations are still in progress.

The knowledge gained from this flows into the development of enhanced performance cryogenic phased array radar systems and has the potential to decisively help other research fields to progress as well.

1 *Experiments with liquid nitrogen.*
2 *View of an individual receive channel built into the large measuring dewar.*
3 *Individual receive channel with fitted cavity backed stacked patch antenna.*
4 *The heated load on the 20 K experimental surface surrounded by the 77 K radiation shield.*

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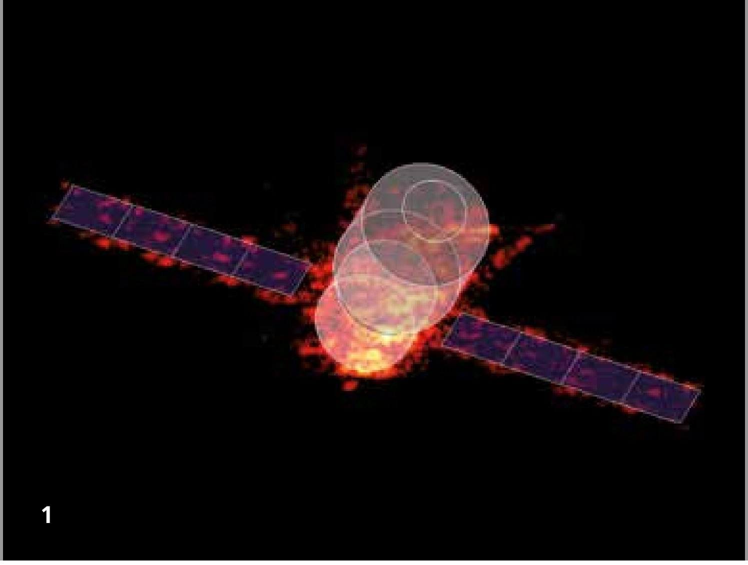
RESEARCH REPORT



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MONITORING THE RE-ENTRY OF THE CHINESE SPACE STATION TIANGONG-1 WITH TIRA

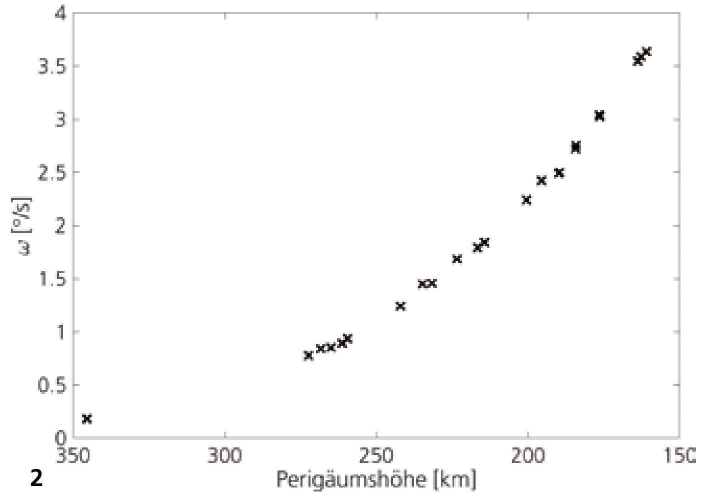
The media spotlight was on the Chinese space station Tiangong-1 as it entered the Earth's atmosphere and crashed on Easter 2018. In this process, Fraunhofer FHR supported the German Space Situational Awareness Center and the European Space Agency (ESA) with up to date, highly accurate orbit parameters and data about the station´s rotation behavior.

The formerly manned Chinese space station Tiangong-1 was brought into orbit in 2011 to a height of approximately 360 km. As of spring 2016, the station was considered to be uncontrolled and thus no further orbit corrections were made. Finally, on April 1, 2018, Tiangong-1 burned up to a large extent in the Earth's atmosphere, and remaining individual fragments possibly fell into the Pacific Ocean. According to current research, the location where a space object will crash onto Earth can only be predicted with a high degree of uncertainty. Low satellite orbits are subject to outside influences that change significantly. The Earth's atmosphere is still present at these heights, even though less than at ground level, gradually slowing down the object. This braking effect leads to a lowering of the orbit. Because of the denser atmosphere at lower heights, the braking force increases continuously, and thus the lowering accelerates as the height decreases.

Fraunhofer FHR regularly supports authorities and international organizations with up-to-date data during the preparations and finally all the way up to re-entry. With the high-performance radar TIRA, the orbit data is accurately captured, while the objects are also imaged using ISAR procedures. In the case of Tiangong-1, Fraunhofer FHR worked with the Space Situational Awareness Center of the German Armed Forces and ESA. In addition, Fraunhofer FHR carried out its own observations for research purposes.

At the beginning of the re-entry phase, the effects caused by the Earth's atmosphere, are relatively low. By entering into denser atmospheric layers, these effects increase significantly, and the observation intervals have to be shortened accordingly to make a good prediction of the re-entry time. Then, just before the re-entry, each flyover is tracked. This was also the case for Tiangong-1, as the last visible pass was picked up by TIRA on Easter Sunday at 9:49 a. m. local time.

The calculated orbit parameters and the current predictions were promptly transmitted to the Space Situational Awareness Center, which was able to use the data for its own re-entry predictions. Within the scope of the campaign, Fraunhofer FHR determined orbit data sets for this purpose and also regularly checked the condition of Tiangong-1 based on radar images. Currently, Fraunhofer FHR is the only entity making this type of radar images available to the public. Thus, the published radar images of Tiangong-1 attracted attention around the world.



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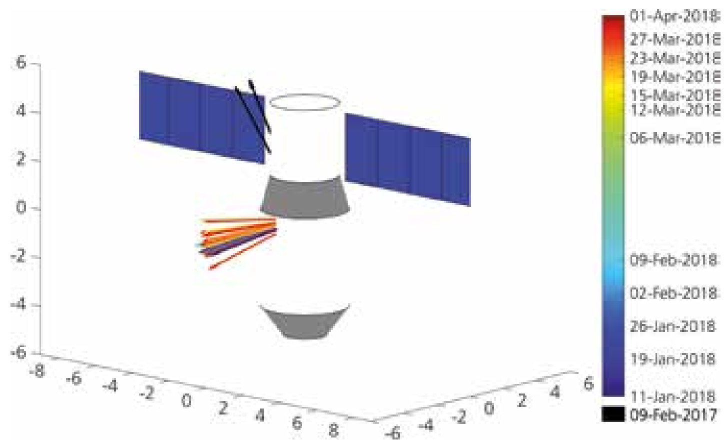

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In addition, TIRA was used to systematically study the rotation behavior of a space object during re-entry for the first time. Because of a possible rotation, the cross-sectional area that is streamed against can change over time, and this can affect the re-entry time. The complete rotation vector, i. e. the rotation axis as well as the rotation speed, and the position in space can only be captured by means of imaging radar methods. In an iterative process, the rotation vector is calculated by means of a series of images created during a pass. By adapting a 3D model of the object to such an image series, the rotation vector can be determined for each observation. Figure 1 shows a radar image with a transparent, overlaid 3D model. This provides for the correct scaling of the radar images on one hand and for the use of the determined rotation vector to examine the natural rotation of re-entry objects on the other hand. In the case of Tiangong-1, which Fraunhofer FHR had been observing for more than one year, it was possible to calculate the corresponding rotation vectors for 24 observations. Figure 2 shows the rotation speed depending on the orbit height. With a decreasing orbit height, a significant increase in rotation speed becomes evident, in particular towards the end of the re-entry phase. Figure 3 shows the respective position of the rotation axis in relation to the object coordinate system. During a large part of the re-entry phase, the rotation axes are perpendicular to the solar panel plane.

In a next step, Fraunhofer FHR will examine the extent to which the re-entry predictions for re-entering objects can be improved by taking into account the information about the orientation and the intrinsic rotation of spacecraft.

1 *ISAR image with overlaid 3D model.*

2 *Rotation speed.*

3 *3D model with rotation axes in the object coordinate system.*

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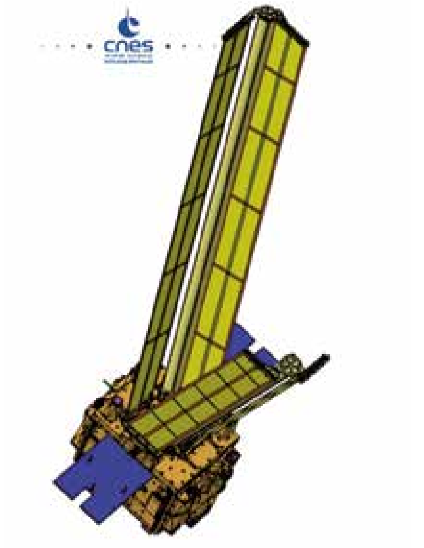

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SUPPORTING SATELLITE DEORBITING MISSIONS WITH TIRA

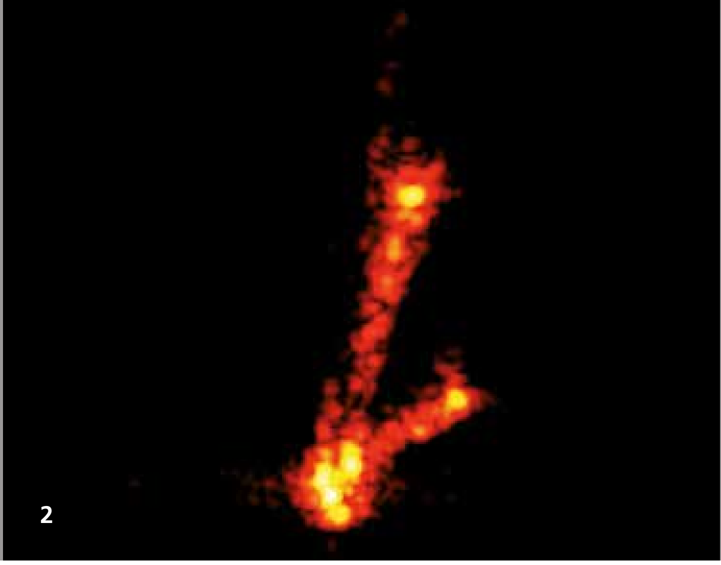
When a mission is over, satellites become space debris and, with this, a danger to active satellites. New deorbiting systems aim to drastically reduce the orbital lifetime. TIRA is capable of reliably verifying the functionality of deorbiting systems for this purpose.

When a satellite mission ends, only space debris is left orbiting the earth. With the dramatic increase in the number of satellites, space debris is also increasing continuously, steadily raising the probability of collisions in low Earth orbit. In turn, with each collision of space debris, the amount of space debris is multiplied, thus permanently increasing the danger for the satellites in use.

Depending on the orbit height, decommissioned satellites can remain in space as space debris for many decades, centuries, or even forever if one does not take suitable measures to initiate a lowering of the satellites to make them burn up in the Earth's atmosphere or other measures directed against space debris. To ensure that the low Earth orbit will still be usable for satellites in the future, an international code of conduct adopted in 2004 concerning the subject of space debris requiring an orbital lifetime of less than 25 years after the end of a mission for the LEO (low Earth orbit). In lower orbits under 600 km, the friction of the satellite in the atmosphere can indeed be sufficient to make the satellite burn up in less than 25 years. In higher orbit, however, this goal cannot be reached without additional measures.

By emitting gas from control nozzles in a controlled manner, deorbiting systems can be used to lower a satellite's orbit to the point that it burns up in the earth's atmosphere. However, active systems are expensive and heavy, increasing the launch costs due their additional weight. That is why active systems are unattractive from an economic point of view, especially for smaller satellites. Therefore, a main focus is currently being placed on the development of passive deorbiting systems, which are cost-effective and relatively light, while increasing the surface-to-weight ratio to the point that they act like brake sails in the very thin Earth atmosphere. For instance, these brake sails can consist of a foil with a thickness of only a few ten micrometers, which will be inflated like a balloon once the mission is over. Thus, these systems are light and can be stored in the smallest of spaces. Compared to active systems, they are also very cost-effective.

The French space agency CNES (Centre National d'Etudes Spatiales) has developed the passive deorbiting system IDEAS (Innovative DEorbiting Aerobrake System) for its satellite MicroSCOPE (Micro-Satellite à traînée Compensée pour l'Observation du Principe d'Equivalence). When the satellite mission ended, two deployable arms consisting of thin aluminum foil were filled with nitrogen. In addition, these arms are equipped with two sails each to increase the surface. This provides a surface of 6.3 m^2 with the complete deorbiting system weighing a total of 12 kg. The two wings are positioned at a specific angle to each other to create the most drag possible. Pressure sensors were installed to check the deployed deorbiting system. These pressure sensors, however, only provide an indirect indication of whether or not the deployment of the wings worked correctly.



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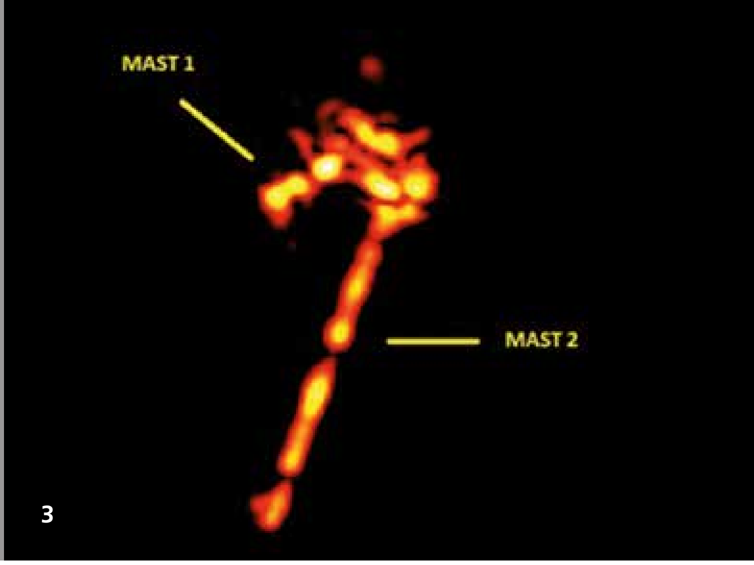

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For this reason, Fraunhofer FHR was assigned with the task of creating images of the satellite with its space radar TIRA to verify the correct deployment of the wings. TIRA's Ku-band radar took images of MicroSCOPE in two flyover passages, directly after the deployment of the arms. The 2D radar images obtained by this were then compared to a 3D satellite model in detail and analyzed. This made it possible to not only identify two deployed arms in the radar image with absolute certainty, but also to measure their length and estimate the opening angle between the two arms. And thus, a final analysis together with the CNES was able to verify the correct deployment of the IDEAS deorbiting system based on the TIRA data.

IDEAS is not the only deorbiting system of its kind. Other systems with different sail geometries and dimensions are being developed or are already on active satellites. Fraunhofer FHR has already received additional inquiries for the verification of deorbiting systems, and many more are likely to come. TIRA is ready to successfully support future deorbiting missions.

1 *Model of the MicroSCOPE satellite with deployed deorbiting system and orientation as in the radar image (figure 2).*
2 *Equivalent radar image for the MicroSCOPE model in figure 1.*
3 *Radar image of MicroSCOPE with deployed deorbiting system from another flyover.*

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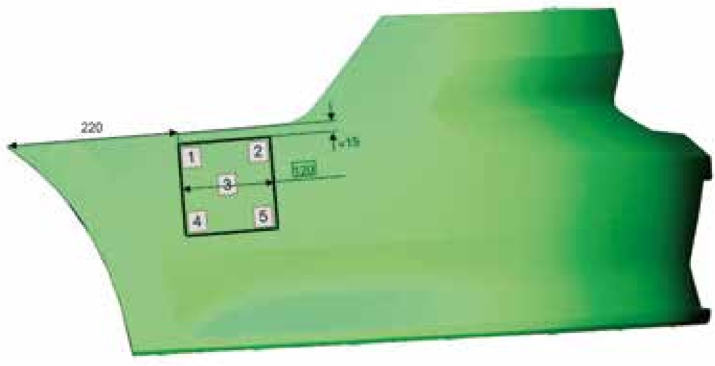

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MATERIAL CHARACTERIZATION FOR AUTOMOTIVE RADAR

Modern driver assistance systems require numerous sensors to increase both safety and comfort. Especially automated driving resorts to optical systems, LIDAR sensor systems, and last but not least radar sensors for environment recognition.

Radar as an Essential Sensor Component

Thanks to its special properties with regard to the robustness against weather influences and its independence of the time of day as well as the reliable characterization of the targets, radar is still an indispensable constant in the sensor group. Particularly, when compared to the optical and infrared spectrum, millimeter waves feature a good penetration in rain, snow, fog, or smoke. In vehicles, radars are usually installed in the bumper. Thus, understanding the transmission and absorption characteristics of the used materials becomes especially important to also ensure the performance of the radar sensors at the installation location.

In the recent past, Fraunhofer FHR has examined this subject intensively in several projects and developed suitable material characterization methods together with suppliers, OEMs, and measuring device manufacturers. In the process, among other things, different planar single and multilayer plastic samples of bumpers were measured in the 75 - 85 GHz range regarding their complex dielectric constant (permittivity). However, not only the plastic material itself, but also its geometric properties such as the curve radii affect the radar signals. In this context, planar samples were compared to samples with different curve radi and examined. When the effects of paint or a primer layer on the transmission and reflection properties of the samples were studied, it was revealed that both values can significantly deteriorate when a cover layer is added. Furthermore, plastic samples coated with a chrome foil (single and two-sided coating) were analyzed. For this purpose, measurements were carried out with and without foil to obtain quantitative results. The measuring results showed that the chrome foil can have a strong effect on transmission losses.

Characterization of Vehicle Emblems

Emblems act as an essential identification feature and are an indispensable component of automobile manufacturers. Long range radars (LLR) are usually installed centrally in the radiator grill, behind the installation point of the emblem, and thus the high frequency characteristics of the emblem are of particular interest. The emblem protects the radar like a kind of second radome but it can also adversely affect the transmitted radar signals.

In a joint project with the company Hyundai Mobis, a wide range of different emblems was characterized. This was done by means of measurements on one hand and by suitable calculation methods and the development of software-based electromagnetic simulation tools on the other hand. These allow for the optimized design depending on the geometrical factors and utilizing the knowledge of the electromagnetic properties of the materials.

Conclusion

With the increased use of radars in vehicles and their integration at the installation location, material and automobile manufacturers are faced with the challenge of characterizing materials regarding their electromagnetic properties.

Thanks to Fraunhofer FHR's extensive know-how in the area of experimental and metrological material characterization along with its knowledge of the electromagnetic and physical propagation behavior in inhomogeneous plastic materials and through layers of paint, the institute was able to make fundamental contributions toward understanding emblems, their optimized design, and the quantitative assessment of the absorption and transmission behavior of different materials.

1 *A plastic bumper part and the square section used for the metrological characterization of its properties (all dimension specifications in mm).*

2 *Metrological setup for the measurement and characterization of plastic parts.*

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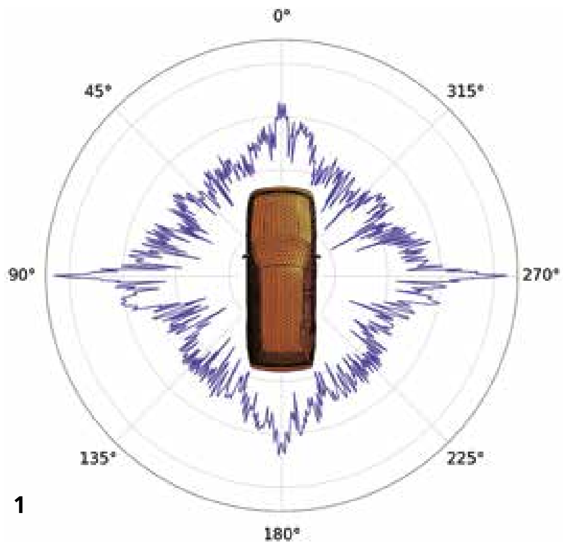

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EM SIMULATION OF DYNAMIC TRAFFIC SCENARIOS

With the simulation tool GOPOSim, a software solution for the fast, electromagnetic simulation of time-dynamic processes is being developed at Fraunhofer FHR. The tool makes it possible to test the function of an automotive radar sensor with synthesized radar data outside of time-consuming test drives.

Automotive radar sensors are an essential component in numerous driver assistance systems already in use today and play a central role for the development of autonomous driving, alongside of LIDAR sensors and camera systems. The used radar sensors have to be able to detect and resolve the environment. The reliable operation of these radar sensor systems can be examined using hardware-in-the-loop or software-in-the-loop tests based on simulated data.

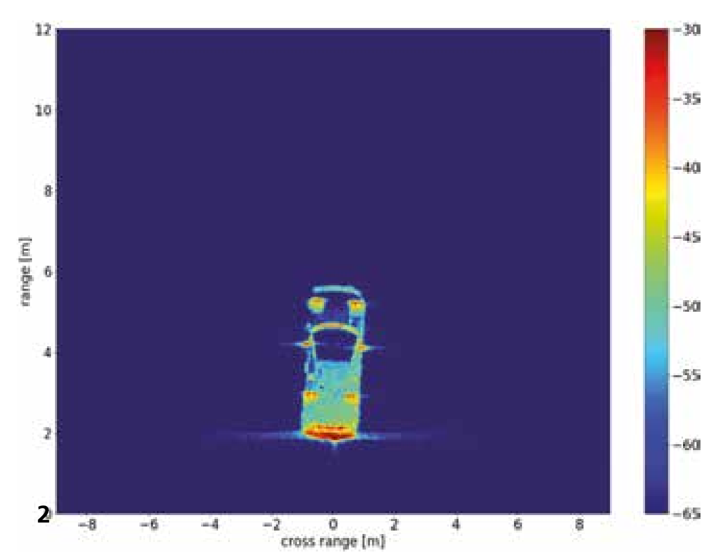
To be able to determine the properties of the radar signatures generated by road users, traffic scenarios have to be modelled and analyzed from an electromagnetic point of view. The software GOPOSim, which uses a deterministic analytical ray tracing approach, allows for the simulation of time-dynamic traffic scenarios. To achieve efficient modelling and short simulation run-times, CAD models of the road users positioned in the corresponding traffic scene are loaded during the run-time and transferred into a suitable scattering center model. This way, GOPOSim calculates the radar signatures of the traffic scenarios in a time-discrete manner, considering the physical properties. The time-dependent course of the scene to be simulated is described with a corresponding trajectory of the simulation objects. To ensure a continuous course of the simulation objects' location, the trajectory is defined in the three-dimensional reference system with a starting position, a vectorial starting speed, and any number of overlaid vectorial accelerations, each valid for a set time interval. For a moving vehicle, the wheels are described separately. The same trajectory is assigned to them as the associated vehicle. In addition, the wheels receive an overlaid rotating trajectory to account for micro-Doppler effects in the electromagnetic simulation of the traffic scene. The micro-Doppler signature allows for the classification during the later signal processing of the data.

Simulation Approach

The simulation of the time-dynamic processes is based on the ray tracing algorithm and on physical optics (PO). This way, the realizable ray paths are generated for each discretized time step according to a deterministic analytical ray tracing approach. For the calculation of the ray paths, multipath propagation can be taken into consideration up to a certain degree. This makes it possible to model interactions of the simulation objects that occur as reflections on road surfaces, for example. The scattering behavior of the simulation objects is calculated for the run-time based on the PO.

Applications

GOPOSim is primarily designed for the simulation of time-dynamic processes. The simulation results can be output in different formats. For instance, after the raw data has been processed, the received radar signal can be processed as a



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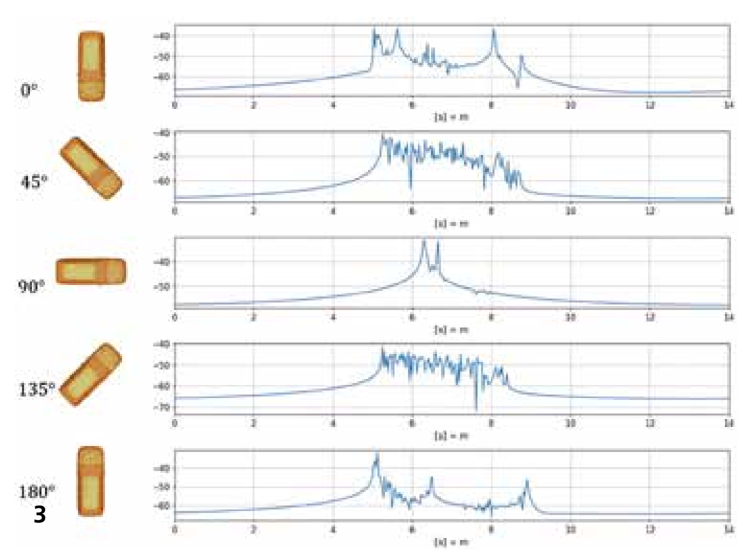

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range-Doppler map, as a Doppler signature, or as an HRR (high range resolution) profile. Figure 2 shows an ISAR (inverse synthetic aperture radar) image of a Golf III, while figure 3 shows different HRR profiles of the vehicle depending on the viewing angle. By using the RTS (radar target simulator) format, the radar target simulator ATRIUM® developed at Fraunhofer FHR is fed, for example. Thus, critical traffic scenarios are played to a radar sensor via a suitable antenna arrangement. For this, the radar target simulator analyzes the signal emitted by the radar sensor, synthesizes the corresponding response to the scene, and sends it back to the radar sensor.

In addition, the software makes it possible to calculate the monostatic as well as the bistatic RCS (radar cross section) of objects available in a CAD model and visualize these as a function of the angle. Figure 1 shows the RCS of a Golf III with a resolution of 720 angle steps 360° around the vehicle. Additional interfaces, e.g. for »software-in-the-loop« simulations will be implemented at Fraunhofer FHR in the future. The electromagnetic simulation of time-dynamic processes, however, requires large computing capacities and enormous computing times.

The ability to use an EM simulation software as a Co-simulation for traffic simulation requires a computing speed that is at least as fast as the real-time sequence of the scene (real-time simulation). This requirement is currently already being fulfilled for traffic scenarios with a limited complexity. GOPOSim will be further accelerated in the future using suitable GPU programming in order to ensure the fulfillment of the real-time requirement for complex scenes as well.

1 *Radar backscattering cross-section Golf III.*

2 *ISAR image Golf III.*

3 *HRR profile Golf III.*

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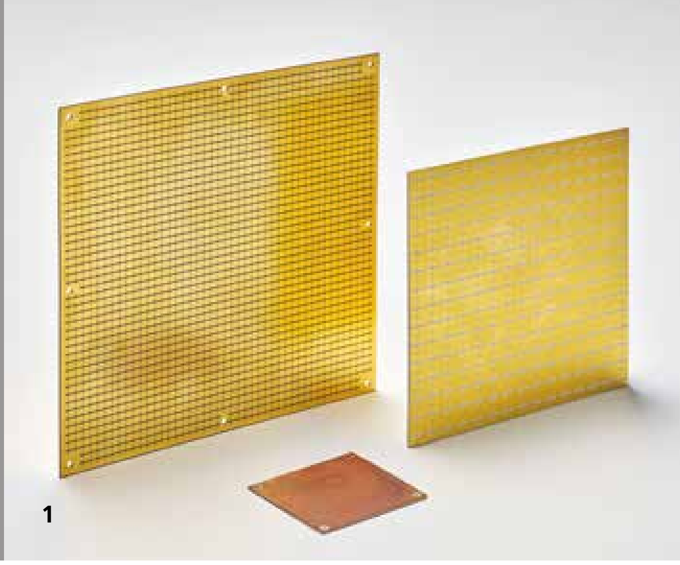

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POLARIMETRY WITH PERFORM

The use of the polarization of electromagnetic waves for radar measurements offers great potential for the detection and classification of targets in heterogeneous scenes. PERFORM makes radar polarimetry available at a low cost and allows for a later integration into existing systems.

Even for modern radar systems, the detection, distinction, and characterization of radar targets always presents a particular challenge when these radar targets are located in a very heterogeneous environment. Radar polarimetry is showing promise in this area, as it is capable of characterizing radar targets to a significantly larger extent than conventional radars.

Every object scatters a radar signal back in its own characteristic manner. All radar systems use this physical principle: They use various signal processing algorithms to determine the distance, speed, position, size, and/or shape of the radar target based on the reflected signal. The more heterogeneous the radar scene is, higher shall be the complexity in separating and filtering the superimposed reflected waves undergoing different scattering mechanisms. Polarimetric radars can distinguish targets better from each other and identify them in these types of situations. Unlike conventional radars, differently polarized high-frequency signals, i. e. electromagnetic waves with different directions of oscillation, are transmitted and received by polarimetric radars. Due to scattering and propagation mechanisms, there is a characteristic change in the polarization. The polarization separation at the receive side and the subsequent polarimetric analysis by means of suitable decomposition procedures allow for the identification and classification of objects and propagation phenomena. This significantly increases the contrast range of a scene. It is even possible to detect concealed targets not recognizable with classical sensors, as long as they change the polarization of the incoming wave.

This principle is already being applied in remote sensing and for weather radars. In remote sensing, this allows for the discrimination and classification of radar targets such as artificial infrastructure developments and vegetation or for the separation and characterization of different landscape and vegetation features in precision farming. Meteorological radar systems use polarimetry to detect different precipitation particles in order to distinguish between hail and rain, for example. However, current polarimetric radar systems are complex and more expensive as well as more prone to failure than conventional radars because of the significant additional hardware requirements.

For this reason, with PERFORM, Fraunhofer FHR has developed a purely passive reflector that can be placed in front of the transmitting and/or receiving antenna of a radar system and changes the polarization of the electromagnetic waves without additional switches or transmit and receive paths. The control of the polarization is solely carried out via different frequency bands. The reflector is based on an array consisting of coupled resonators that cause either a direct reflection or a resonator-based rotation, depending on the frequency band used. The significantly reduced hardware requirements make it possible to implement more cost-efficient, compact, and robust polarimetric radars.

Besides geological and meteorological questions such as monitoring and characterization of infrastructure, biomass, forest

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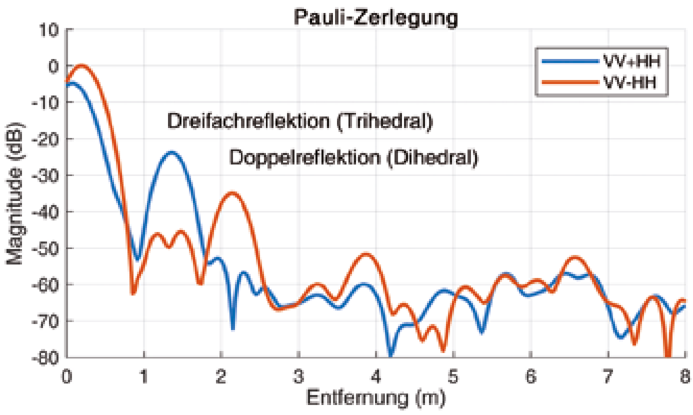

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areas, ice surfaces, or atmospheric layers, other promising polarimetric applications are possible in the areas of autonomous driving, space surveillance, or defense. Existing radar systems can be retrofitted with a PERFORM reflector at a low cost. A patent application has been filed for the system because of its degree of innovation and its variety of application possibilities.

Several prototypes have already been developed successfully in the Ku-band (14.1-15.9 GHz), the Ka-band (32.9-37.1 GHz), and the E-band (77.0-81.0 GHz), proving the functional principle based on a good consistency between simulations and measurements. In the coming months, a prototype in the Ka-band will be used for polarimetric SAR measurements from the air to produce first radar images.

This is how Fraunhofer FHR is unlocking radar polarimetry for its clients and partners, helping their radar systems to achieve a significantly better view due to the optimal adaptation to the individual task fields.

1 *PERFORM reflectors for the Ku, Ka and E-bands.*

2 *Arrangement for measurements in the E-band. The holder on the right encloses a linearly polarized horn antenna to which a radar can be connected.*

3 *Distance profiles captured with an E-band measuring arrangement. The polarimetric analysis made it possible to distinguish a double and a triple reflector.*

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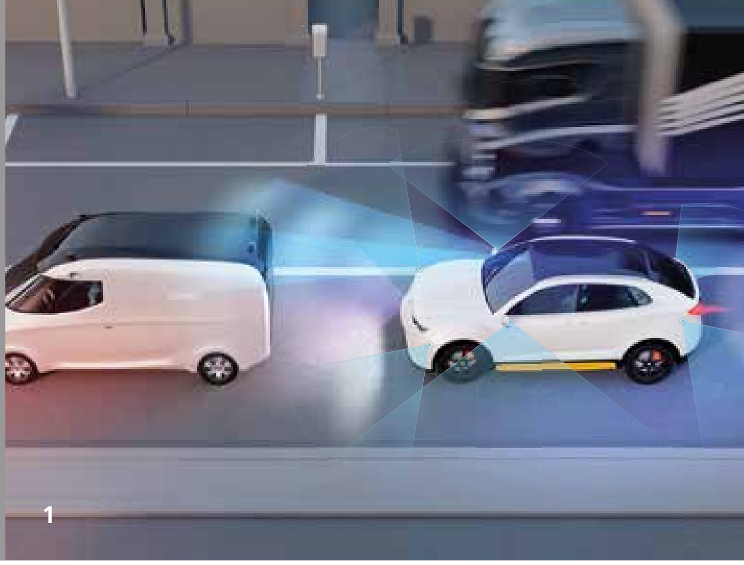


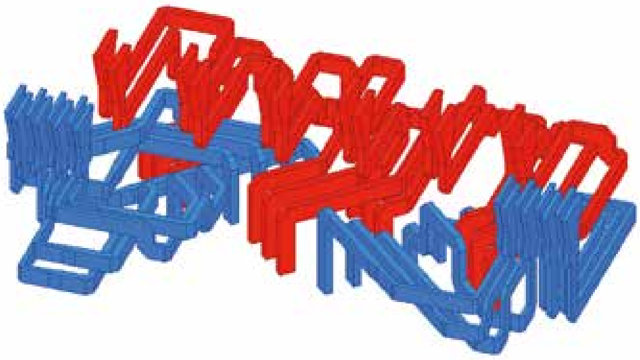
ANTENNA DEVELOPMENT FOR FUTURE AUTOMOTIVE RADARS

Radar is the most important sensor for autonomous driving. A high spatial resolution capacity is achieved by using a large number of antennas that all have to be connected with individual ports of integrated radar ICs. When laying out the complex high frequency connection networks, the printed circuit board technologies used so far come up against their limits.

The vision of autonomous driving is now within reach. This is made possible by the intelligent fusion of a series of different active sensors such as LIDAR and radar as well as sensors based on ultrasound in combination with passive sensors such as cameras, accelerometers, speedometers, receivers for the global navigation satellite systems (GNSS) in connection with digital maps and the vehicle's data exchange with its environment (car-2-x communication). Radar plays a special role among the active sensors. Some of the advantages – besides the relatively low costs – are its all-weather capability, the range, and the variety of information that can be extracted from radar signals.

In radar engineering, a large number of different procedures is known that can be used to determine the position, speed, and special properties of a single object and to separate multiple objects from each other. In the automotive sector, a combination of frequency-modulated continuous wave signals (FMCW) for the determination of the distance and radial speed with a direction determination based on the comparison of the receive phase of several receiving antennas (digital beamforming) has established itself due to cost reasons. Separate transmitting and receiving antennas are usually used for this. The minimal configuration consists of one transmitting antenna and two receiving antennas. The receiving antennas are arranged at a horizontal distance of half a free-space wavelength. This way, under ideal conditions, individual objects can be detected in the horizontal plane. To counteract deteriorations of the wave propagation conditions, for instance those caused by an antenna cover (radome) or an additional plastic cover (manufacturer's emblem, bumper, etc.), manufacturing tolerances, or dirt, and to be able to separate multiple reflections in the same radial distance at different angles, usually three or more receiving antennas are used. The arrangement of the receiving antennas can also be staggered in the vertical direction. This offers the possibility of also measuring the height of objects above the ground.

Finally, the next configuration level uses several transmitting antennas at different positions. Through the smart spatial distribution of the transmitting and receiving antennas, a virtual array antenna can be generated according to the multiple-input/multiple-output (MIMO) principle. The spatial resolution capacity of this array antenna is significantly better than what would be possible with the real aperture of the radar sensor. The manufacturers of automotive radar sensors are currently working on systems with 12 transmitting and 16 receiving antennas, for example. The highly integrated circuits (MMICs) with FMCW radar signal generation und the corresponding receivers are currently offered by several large IC manufacturers such as Infineon, Texas Instruments, or NXP. These MMICs typically feature three independent transmit and



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four receive channels. As a consequence, one of the radar sensors mentioned above can be built using four of these MMICs.

Typically, due to cost reasons, printed radiating elements such as microstrip antennas or slotted surface-integrated waveguides (SIW) are used as antenna elements because they can be integrated monolithically with the radar MMICs and possibly other electronic components on the same printed circuit board. With the large number of antenna-elements the current generation of radar sensors wants to use, however, the arrangement of the RF lines between the MMICs and the antennas becomes a major challenge. Because of the large number of necessary layers, layer changes, and especially the transmission line losses, a solution based on printed, multilayer circuits seems unrealistic.

On behalf of the company Continental ADC Automotive Distance Control Systems GmbH, Fraunhofer FHR has developed a first step towards an antenna solution based on milled, metallic waveguides and sectoral horn antennas. To begin with, the complex feed network between MMICs and antennas was implemented as a layer structure in aluminum. A specially adapted cover made of radar absorbing material of the unused parts on the antenna side of the waveguide circuit is designed to simplify the installation of a radome and the integration in a vehicle. The full wave simulation and the measurement of the antenna properties have revealed a high radiation efficiency, a low mutual antenna coupling, and very smooth radiation patterns. The first radar experiments were very promising. The next development stage will now focus on the cost-efficient manufacturing with other materials and procedures.

1 *Radar sensors with a good spatial resolution are indispensable for the safety of autonomous vehicles.*

2 *Automotive MIMO radars based on today's MMICs require complex networks of RF transmission lines to connect a large number of individual antennas. Waveguide technology offers a high degree of flexibility and minimal losses in this area.*

3 *A first prototype of a waveguide antenna with a complex RF feeding network was developed, implemented and characterized at FHR.*

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RESEARCH REPORT

1

NEW IMPULSES IN MAGNETIC RESONANCE IMAGING WITH METAMATERIALS

Magnetic resonance imaging is by far the most high-performance imaging technology, but it is also the technically most challenging one. New concepts based on the use of metamaterials make it possible to open up new fields of application and overcome the limitations of established procedures.

In medical imaging, magnetic resonance imaging (MRI) has become an indispensable instrument in clinical diagnostics and in certain areas also in therapeutic support. On the one hand, this is due to the seemingly inexhaustible variety of the contrast mechanisms that reach from the presentation of morphological structures (even below the actual resolution limit!) to physiological and physical processes (blood circulation measurements, diffusion processes, elasticity, etc.). On the other hand, an important argument is found in the completely non-invasive functional principle and the harmlessness for the human body in contrast to many other medical imaging methods (such as computer tomography, positron emission tomography, or scintigraphy with their ionizing radiation). However, this is at the expense of the substantial technical effort necessary for high-quality MRI images. MR scanners are by far the most technically sophisticated devices in medical diagnostics. The strong magnetostatic field used to »generate« the macroscopic nuclear magnetization as well as the time-variable magnetic field gradients and the radio frequency waves to »excite« the magnetization interact with the body of the patient and potential other devices located in or close to the MR tomograph. Costly technical solutions are necessary to prevent physical impairments of the patient while providing high quality images. The possibilities of the current art of engineering seem to be exhausted to some extent here, since in some areas there have been no significant improvements for many years now. In this context, it is worth mentioning RF chokes as well as the basic principle of spatial coding in MRI.

New concepts to solve typical problems in MRI can open up new fields of application and also overcome the limitations of existing approaches. In recent years, a new »class« of materials with special properties has attracted attention as these materials can be used to rethink many problems. In medical technology, this class of materials has until now only been studied in individual research groups, while it has not been possible to reach commercial maturity yet. We are talking about so-called metamaterials (MTM).

The spectacular peculiarity of metamaterials is that they make it possible to obtain artificial materials with effective properties that can be tailored to the individual application. Even material properties can be produced that usually do not exist in nature. For RF metamaterials, these macroscopic electromagnetic properties are created by microscopic, usually periodic circuit structures that can be realized with cost-effective standard printed circuit board manufacturing techniques, for example. Some of the electromagnetic effects that can be achieved this way are negative refractive indices that allow for a perfect focusing far beyond the diffraction limit or for frequency bands in which wave propagation is suppressed.

In an internal Fraunhofer research project, the Fraunhofer Institute for Digital Medicine MEVIS and the Fraunhofer

Institute for High Frequency Physics and Radar Techniques FHR are cooperating to explore the application possibilities of MTM technologies to improve MR imaging and develop product-related solutions based on this. The goal is to allow for the use of any type of electrical lines within MRI without interferences, while also improving the signal-to-noise ratio in the relevant volume ranges. Moreover, special metamaterial lenses are being developed that might be able to facilitate a fundamentally new MRI concept. Finally, based on the developed solution concepts, the goal is to create a flexible design platform for further MTM applications in the MRI area in the middle and long term.

1 *Typical magnetic resonance tomograph with the characteristic, superconductive permanent magnet and the patient table.*

2 *Example of a typical MRI image. The individual tissue types can be identified through the different grayscales.*

3 *Fraunhofer FHR has extensive measuring equipment for the examination of the effectiveness of new metamaterial-based approaches for high frequency problems in MR imaging.*

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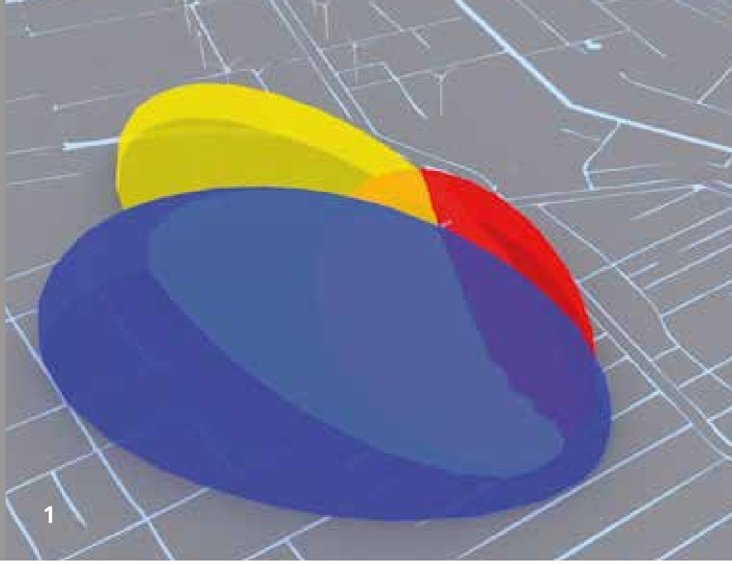
RESEARCH REPORT



PASSIVE RADAR CONTROLS THE NIGHTTIME IDENTIFICATION OF WIND TURBINES

Wind energy is an important pillar of the energy transition. However, affected residents tend to reject it, in particular because of the bothersome red warning lights that flash at night. The passive radar system PARASOL for the needs-based nighttime identification, accredited by German Air Traffic Control, can provide an environmentally friendly and cost-conscious remedy.

Obstructions to aviation such as wind turbines higher than 100 meters have to be specifically marked at night with flashing red lights. In most cases, this is only necessary in less than 1 - 2 percent of the time, i.e. only when an aircraft is actually approaching the wind farm. Other systems available in the market detect these aircraft using active radars. Since these systems replace the visible radiation of the lights with the invisible radiation of the active radars, residents still reject them just like the lights. This has led to the fact that the currently offered active systems are not selling as desired. The passive radar system PARASOL, which was developed in collaboration with the wind farm operator Dirkshof in Reußenköge and with the support of the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU), is a better solution without additional emissions.

The PARASOL System

The PARASOL system – where PARASOL is the German acronym for passive radar-based control of object identification for aviation – uses existing radio and TV signals to detect approaching aircraft without any additional electromagnetic emissions. Therefore, no expensive frequency assignments and site certifications according to § 4 of the German order on the means of providing proof in regard to limiting exposure to electromagnetic fields (BEMFV) are required. The used DVB-T, DVB-T2, and DAB+ networks are already widely available. The result was a warning system that is especially environmentally friendly and cost-conscious, while also – and most notably – promoting acceptance among the population.

Fraunhofer FHR has years of experience in the area of passive radar, in particular in the use of modern digital radio networks. By selecting reliable system components and stable as well as real-time algorithms, it was possible to perfect this work, which had begun as a feasibility study, and make it market-ready. This finally culminated in the accreditation of the system by German Air Traffic Control (DFS) in May 2018. Since then, the first installation is doing its job in the Reußenköge wind farm, and many others will follow.

Mode of Operation

At the wind farm Reußenköge, the DVB-T2 stations Flensburg und Kiel can be received primarily. The PARASOL sensors capture the signals of these TV stations as well as their echoes from aircraft. In the process, the echo signals have a time delay due to the detour of the signal, as well as a Doppler shift due to the movement of the aircraft. After reconstructing the emitted signal, it is correlated with the echoes received. Based on this, the parameters detour and Doppler shift are measured. The precise three-dimensional locating of an

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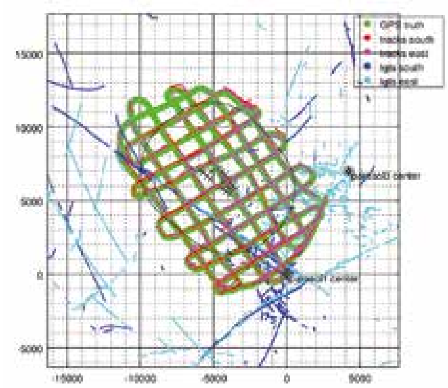

3

aircraft would require the reception at a sensor with an antenna that allows for direction determination. Instead, an arrangement with three sensors was chosen to allow for the use of a simple hardware setup that does not require maintenance or extensive calibration. Each sensor consists of a simple receiving antenna, a receiving unit as well as a standard computer. The sensors communicate with each other via a network at the wind farm and determine the position of any aircraft using an ellipsoid intersection method.

Two of these sensor triples were installed at the Reußenköge wind farm to cover the entire wind farm with a size of about 120 square kilometers. One sensor reaches an individual range of up to 15 km for aircraft with a radar backscattering cross-section of 1 square meter (microlite). A particular challenge here was the development of reliable methods that provide for the detection of these small targets in the surroundings of the rotating wind turbines.

Planning of PARASOL Installations

For the targeted planning of PARASOL installations, a software was developed that allows for the determination of preferred sites for the setup of passive radar sensors. The easy installation of the sensors makes it possible to choose the sites freely, independent of existing wind turbines or buildings. However, the sensors can also use existing infrastructures to be integrated into existing environments.

Further Use of PARASOL

PARASOL ensures a reliable operation as a detector for smaller aircraft in areas surrounding wind turbines. That is why its use for the detection of drones in the field of property protection will be examined at Fraunhofer FHR in the future. There is potential here for the use of light, mobile sensors with a more advanced deployment software to set up a surveillance system with a short start-up time.

1 *Intersection of three ellipsoids for 3D locating.*
2 *Permanently installed and mobile antenna unit.*
3 *Flight around the wind farm for the DFS accreditation.*

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MINIATURE MIMO RADAR SENSORS FOR THREE-DIMENSIONAL VISIBILITY IN HARSH ENVIRONMENTAL CONDITIONS

The European Horizon 2020 research project SmokeBot was concluded in June 2018 with a successful demonstration in the fire exercise building of the Dortmund fire department. Fraunhofer FHR proved to be a reliable partner in the area of integrated MIMO radar modules.

Sensor Suite for the Exploration of Buildings Filled with Smoke

The project has pointed out new paths in sensor technology to provide robots with reliable orientation, create maps, and thus save lives even in parts of a building completely saturated in smoke. The project was coordinated by Achim Lilienthal, Professor at the Swedish Örebru University. Within the scope of the SmokeBot project, the project team equipped a robot provided by the Austrian company TAUROB with a multitude of environment exploring sensors. Besides laser measuring technology, infrared cameras, and gas sensors, this sensor suite also included a highly integrated MIMO radar from Fraunhofer FHR.

Technological Advantage thanks to Silicon-Germanium Integration

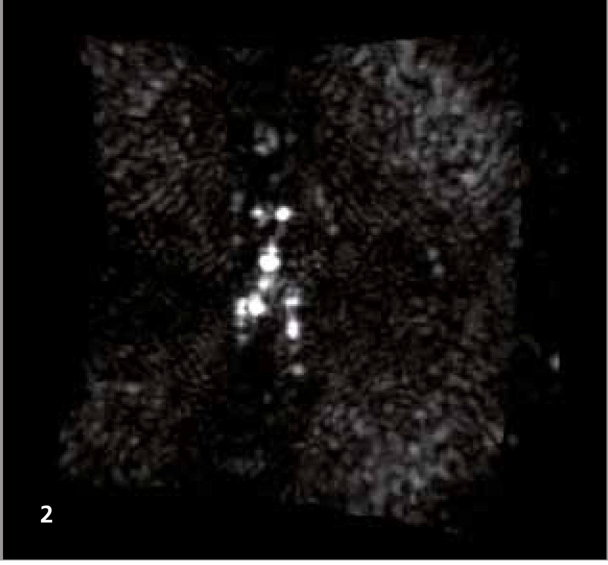
In this process, the development at Fraunhofer FHR already started at the chip level. The researchers developed a complete MIMO chip set with an operating frequency of 120 GHz. Each chip contains either 4 transmit or 4 receive channels on a total size of less than 2x2 millimeters. Thanks to this technology, the team of researchers was able to implement 24 transmit and 24 receive channels with a total module size of only 25 cm, thus providing 576 combinations for angle-resolved imaging. The individual pulses based on linear frequency chirps were optimized to provide for the sequence of all 24 transmission pulses within less than three thousandth of a second.

Both, the high frequency electronics as well as the data collection were accommodated in the modules thanks to the use of compact digital circuit electronics. In addition, Fraunhofer FHR developed its own concepts for the synchronization of all 24 receive channels. It was possible to directly integrate the antenna elements into the housing.

This way, despite their internally very high complexity, the developed modules can easily be integrated into the measuring systems. The system has to provide one single supply voltage and a standard network interface for this.

3D Obstacle Recognition Thanks to Digital Image Reconstruction Algorithms

Each measurement data set is processed to calculate a three-dimensional image using the 3D near field reconstruction algorithms developed at Fraunhofer FHR. This allows for the reliable locating of objects, doors, or walls even through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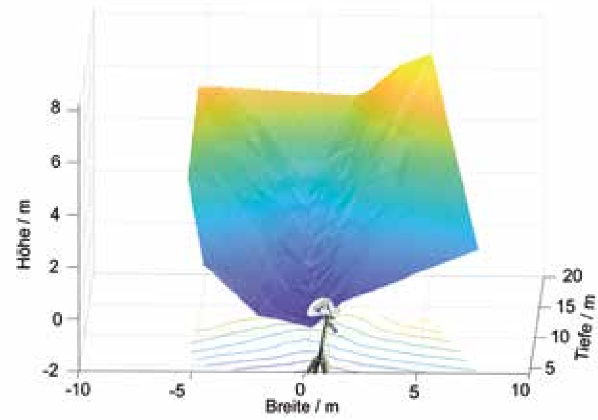

smoke, fog or backlight. The image quality largely depends on the antenna arrangement. A small antenna array with a high density of transmitter and receiver elements offers very high image dynamics, while the distribution of the antennas across a larger area provides for a higher image resolution at the expense of lower image dynamics. The SmokeBot team at Fraunhofer FHR chose a semicircular distribution of the antenna elements developed specifically for the project. This allows to obtain an image resolution of less than one degree over a field of view of 45 degrees in all directions, even with only 24x24 channels. In the process, the special antenna arrangement distributes the imaging artefacts caused by the thinned-out aperture as evenly as possible across the entire angular range. This results in imaging dynamics of 17 dB.

Numerous Applications from the Detection of Humans up to Surface Reconstruction

Figure 2 shows what this means with regard to the image quality. A person was captured by a single radar measurement. The outline of the standing person can be made out clearly thanks to the high resolution. However, there are image artefacts around the person caused by the sparse antenna array. Nevertheless, the person clearly recognizable. Because of the short data acquisition time, the tracking of movement is one possibility of gaining a large amount of information from the data. Another application consists of the outstanding suitability of the radar technology for the scanning of rough surfaces. Figure 3 shows the three-dimensional capture of an ore deposit. For optical technologies, it is especially hard to capture dark surfaces outdoors. Here, a radar-based solution offers a significantly higher reliability. The possibilities of the newly developed technology prove to be diverse and are bound to open up numerous other research and application fields.

Successful Demonstration Even in Zero Visibility Conditions

On the occasion of the final review meeting at the end of June, the entire system was demonstrated in the fire exercise building of the fire department. In this demonstration, Fraunhofer FHR's MIMO radar was able to showcase its full capacities. Even when the building was completely filled with smoke and the LIDAR sensors as well as the installed cameras no longer provided an evaluable signal, Fraunhofer FHR's radar technology ensured the reliable operation of the complete system.

1 *High Resolution MIMO module with 24 transmitter and 24 receiver elements.*
2 *MIMO radar image of a single person.*
3 *Reconstructed 3D profile of an outdoor ore deposit.*

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PUBLICATIONS

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

All publications 2018:
www.fhr.fraunhofer.de/publikationen2018

Publications in scientific journals
www.fhr.fraunhofer.de/publikationen2018-journals

Publications in scientific conferences
www.fhr.fraunhofer.de/publikationen2018-konferenzen

All Fraunhofer publications:
http://publica.fraunhofer.de

EDUCATION AND TRAINING

Lectures

WS 2017/2018

Bertuch, T.: „Antennen und Wellenausbreitung“, FH Aachen, WS 2017/2018

Bongartz, J.: „Signalverarbeitung“, HS-Koblenz, WS 2017/2018

Bongartz, J.: „Medizinische Gerätetechnik“, HS-Koblenz, WS 2017/2018

Caris. M.: „Physikalisches Praktikum“, Hochschule Bonn-Rhein-Sieg, WS 2017/2018

Cerutti-Maori, D.: „Signal processing for radar and imaging radar“, RWTH Aachen, WS 2017/2018

Ender, J.: „Radar – Techniques and Signal Processing I (Radarverfahren und -Signalverarbeitung I)“, Universität Siegen, WS 2017/2018

Heberling, D.: „Hochfrequenztechnik 1“, RWTH Aachen, WS 2017/2018

Heberling, D.: „Moderne Kommunikationstechnik - EMV für Mensch und Gerät“, RWTH Aachen, WS 2017/2018

Heberling, D.: „Wat is'n Dampfmachin' Technikphänomene in den Ingenieurwissenschaften (Ringvorlesung)“, RWTH Aachen, WS 2017/2018

Knott, P.: „Antenna Engineering“, RWTH Aachen, WS 2017/2018

Knott, P.: „Radar Systems II“, RWTH Aachen, WS 2017/2018

Lorenz, F.: „Measuring Techniques - Praktikum“, Hochschule Bonn-Rhein-Sieg, WS 2017/2018

Lorenz, F.: „Risikomanagement in der Supply Chain“, EUFH Köln, WS 2017/2018

Pohl, N.: „Integrierte Hochfrequenzschaltungen für die Mess- und Kommunikationstechnik“, Ruhr-Universität Bochum, WS 2017/2018

Pohl, N.: „Elektronik 1: Bauelemente“, Ruhr-Universität Bochum, WS 2017/2018

SS 2018

Bongartz, J.: „Funktionsdiagnostik und Monitoring“, HS-Koblenz, SS 2018

Bongartz, J.: „Lasermedizin und biomedizinische Optik“, HS-Koblenz, SS 2018

Bongartz, J.: „Signalverarbeitung“, HS-Koblenz, SS 2018

Brüggenwirth, S.: „Cognitive Sensorics“, Universität Siegen, SS 2018

Brüggenwirth, S.: „Kognitive Sensorik“, Ruhr-Universität Bochum, SS 2018

Caris. M.: „Physikalisches Praktikum“, Hochschule Bonn-Rhein-Sieg, SS 2018

Heberling, D.: „Elektromagnetische Felder 2 (IK)“, RWTH Aachen, SS 2018

Heberling, D.: „Hochfrequenztechnik 2“, RWTH Aachen, SS 2018

Knott, P.: „Radar Systems I“, RWTH Aachen, SS 2018

Lorenz, F.: „Physics - Praktikum“, Hochschule Bonn-Rhein-Sieg, SS 2018

Lorenz, F.: „Trends der Logistikforschung“, EUFH Köln, SS 2018

Lorenz, F.: „Qualitätsmanagement“, EUFH Brühl, SS 2018

O'Hagan, D.: „Antennas for all applications“, Universitiy of Cape Town; Südafrika, SS 2018

Pohl, N.: „Master-Praktikum Schaltungsdesign integrierter Hochfrequenzschaltungen mit Cadence“, Ruhr-Universität Bochum, SS 2018

Pohl, N.: „Integrierte Digitalschaltungen“, Ruhr-Universität Bochum, SS 2018

Diploma, masters and bachelor theses

Arpe, O.: „Entwicklung eines rotierenden vollpolarimetrischen abbildenden Hochfrequenzsystems im W-Band“, Hochschule Koblenz, Master

Bell, R.: „Aufbau eines abbildenden, rotierenden Scanner-Systems bei einer Mittenfrequenz von 90 GHz“, Hochschule Koblenz, Master

Budoni, M.: „Development and Experimental Testing of an Initial Orbit Determination Algorithm based on Radar and Optical Data“, Universitá La Sapienza di Roma, Master

Carloni, C.: „Kalman Filters for Autonomous Tracking of Space Objects with Radar and Optical Measurements“, Universitá La Sapienza di Roma, Master

Ceyhun, T.: „Risikomanagement von FuE-Großprojekten mit Schwerpunkt Weltraumüberwachungsradar GESTRA“, Technische Hochschule Köln, Bachelor

Fabian, J. N.: „Entwurf und Charakterisierung eines netzwerkfähigen Umweltmonitoring-Systems“, Ruhr Universität Bochum, Bachelor

Lauxmann, L.: „Entwicklung eines Kalibrierverfahrens für dreidimensionale Nahfeldabbildung durch modulare Millimeterwellenscanner“, RWTH Aachen, Master

Minorowicz, M.: „Mikrocontroller-basierte Positionierung eines Mikroskops mit menügeführter Parameteranzeige“, Ruhr Universität Bochum, Bachelor

Reckter, J. S.: „Design dielektrischer Resonator Antennen und Herstellung dieser mittels generativer Fertigungstechniken (3D-Druck)“, KIT Karlsruher Institut für Technologie, Bachelor

Schemer, J.: „Einfluss der Bewegungstrajektorie auf die ISAR-Bildgebung“, TH Trier, Master

Schiraz, N.: „Analyse von DopplerSignaturen im Submillimeterwellenbereich“, Hochschule Koblenz, Bachelor

Saalmann, A.: „Untersuchung zur Erkennung von Flügelschlagmustern von Vögeln in Radardaten“, Universität Koblenz Landau, Master

Schemer, J.: „Einfluss der Bewegungstrajektorie auf die ISAR-Bildgebung“, TH Trier, Master

Schiraz, N.: „Analyse von DopplerSignaturen im Submillimeterwellenbereich“, Hochschule Koblenz, Bachelor

Schuth, K. S.: „Entwurf variabler Verzögerungsleitungen“, Hochschule Koblenz, Bachelor

Schwäbig, C.: „Konzeption und Realisierung eines bildgebenden Millimeterwellenscanners und Entwicklung eines Verfahrens zur echtzeitfähigen Auswertung der Bilddaten“, Hochschule Bonn-Rhein-Sieg, Master

Wallek, J.-P.: „Evaluation der Herstellbarkeit von planaren Millimeterwellen-Schaltungen mit einem Laser-basierten Rapid-Prototyping-System“, Hochschule Koblenz, Master

Wenderoth, J.: „MIMO-Radarfrontend mit integriertem Antennenarray und orthogonaler Wellenformmodulation MIMO-Radarfrontend with integrated antenna array and orthogonal waveform modulation“, RWTH Aachen, Master

COMMITTEE WORK

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

Berens, P.
- European Conference on Synthetic Aperture Radar (EUSAR) 2018, Aachen: Program Committee Member, Awards Committee

Bongartz, J.
- Deutsche Gesellschaft für Photogrammetrie, Fernerkundung und Geoinformation (DGPF): Member
- Deutsche Physikalische Gesellschaft (DPG): Member

Brüggenwirth, S.
- EEE AESS Germany Chapter: Secretary
- International Radar Symposium (IRS) 2018, Bonn: Technical Program Committee
- EDA Radar Captech: German Governmental Expert

Cerutti-Maori, D.
- Inter-Agency Space Debris Coordination Committee (IADC): Vertreterin der ESA in the Working Group 1 (Measurements)
- European Conference on Synthetic Aperture Radar (EUSAR) 2018, Aachen: Technical Programme Committee
- Radar 2018: Technical Programme Committee Member

Danklmayer , A.
- U.R.S.I. International Union of Radio Science, Commission-F Wave Propagation and Remote Sensing, Member
- VDE-ITG Technical Committee 7.5 Wave propagation, Member
- Deutsche Gesellschaft für Ortung und Navigation (DGON), Member of the Technical Committee "Radar technology"
- European Conference on Synthetic Aperture Radar (EUSAR) 2018, Aachen: Technical Program Committee
- IEEE International Geoscience and Remote Sensing Symposium (IGARSS) 2018: Member of the Review Board
- International Radar Symposium (IRS) 2018, Bonn: Technical Program Committee
- IEEE -GRSS, -MTT, -AP-S: Member, SPIE: Member, IEICE: overseas Member

Ender, J.
- International Radar Symposium (IRS) 2018, Bonn: Technical Program Committee
- European Conference on Synthetic Aperture Radar (EUSAR) 2018, Aachen: Technical Program Board
- International Workshop on Compressed Sensing applied to Radar, Multimodal Sensing and Imaging (CoSeRa 2018): Co-Chairman
- Member of the council of DGON (Deutsche Gesellschaft für Ortung und Navigation)
- VDI-ITG Fachbereich 7: Spokesman High Frequency Technology

Gonzalez-Huici, M.
- International Workshop on Compressed Sensing applied to Radar, Multimodal Sensing and Imaging (CoSeRa 2018): Technical Program Committee
- TA 44 Germain-Israeli expert group on „Millimeter and Teraherz Waves: Technology and Applications“

Heberling, D.

- ITG-Technical committee 7.1 „Antennas“: Chairman
- European Conference on Antennas and Propagation (EuCAP) 2018, London: Co-organiser, member of the Steering Commities
- Zentrum für Sensorsysteme (ZESS) 2018, Siegen: Member of the Advisory Board
- Antenna Measurement Technique Association (AMTA) 2018, Williamsburg: President
- Deutsche Forschungsgesellschaft (DFG): Technical Committee
- Member of IMA (Institut für Mikrowellen- und Antennentechnik e. V.)
- Senior of IEEE (Institute of Electrical Electronics Engineers)

Klare, J.

- European Conference on Synthetic Aperture Radar (EUSAR) 2018, Aachen: Technical Program Committee
- International Radar Symposium (IRS) 2018, Bonn: Technical Program Committee
- European Microwave Week (EuMW) 2018, Nürnberg: Technical Review Committee
- International Conference on Aerospace Electronics and Remote Sensing Technology (ICARES) 2018, Bali: Technical Program Committee
- International Conference on Electrical Engineering, Computer Science and Informatics (EECSI) 2018, Yogyakarta: Technical Program Committee
- International Conference and Workshop on Telecommunication, Computing, Electronics and Control (ICW-TELKOMNIKA) 2018, Yogyakarta: Technical Program Committee
- IEEE International Conference on Photonics (ICP), 2018, Langkawi: Technical Program Committee

Knott, P.

- Informationstechnische Gesellschaft (ITG) im VDE, Technical Committee HF 4 „Detection“: Chairman
- IEEE Microwave Theory and Techniques (MTT) / Antennas and Propagation (AP) Joint Chapter, Executive Committee: Chair
- Deutsche Gesellschaft für Ortung und Navigation (DGON) e.V.: Member of Advisory Board, Chairman Technical Committee Radar Technology
- European Association on Antennas and Propagation (EurAAP): Gewählter Regional Delegate
- NATO Research and Technology Organisation (RTO): „Member at Large“ des Sensors and Electronics Technology Panels
- 18. International Radar Symposium (IRS) in Bonn: Chair

Leushacke, L.

- Inter-Agency Space Debris Coordination Committee (IADC): German representative in Working Group 1 (Measurements)

Nüßler, D.

- Deutsche Gesellschaft für Zerstörungsfreie Prüfung (DGZfP): Member
- VDI/VDE-GMA FA 8.17 Terahertz-Systems: Member
- European Machine Vision Association (EMVA): Member
- OCM 2019: Technical Program Committee

COMMITTEE WORK

Pohl, N.

- IEEE Topical Meetings on Silicon Monolithic Integrated Circuits in RF Systems (SIRF 2018), Orlando, USA: Conference Chair
- European Microwave Week (EuMW) 2018, Nürnberg: Technical Program Committee
- International Radar Symposium (IRS) 2018, Bonn: Technical Program Committee
- International Microwave Symposium (IMS 2018), Philadelphia, USA: Tecnical Programm and Review Committee, Student Design Contest Organizer
- IEEE BiCMOS and Compound Semiconductor Integrated Circuits and Technology Symposium (BCICTS 2018), San Diego, USA: Technical Porgramm Committee, CO-Chair for MM-Wave & THz ICs
- VDI ITG Technical Committee 7.3 Micro Wave Technology, Member
- IEEE MTT Technical Committee MTT-16, Microwave Systems, Member
- Member of IMA (Institut für Mikrowellen- und Antennentechnik e. V.)
- Senior Member of IEEE (Institute of Electrical Electronics Engineers)

Rial Villar, F.

- EDA Remote Intelligence of Building Interiors (RIBI): German Governmental Expert

Ribalta Stanford, A.

- European Conference on Synthetic Aperture Radar (EUSAR) 2018, Aachen: Program Committee Member

Uschkerat, U.

- DEA 1670 Counter Mine: Project Member
- EDA Radar Captech: German Governmental Expert

Dr.-Ing. Ingo Walterscheid

- European Conference on Synthetic Aperture Radar (EUSAR) 2018, Aachen: Program Committee Member, Awards Committee
- IEEE International Geoscience and Remote Sensing Symposium (IGARSS) 2018: Scientific Committee Member

Weinmann, F.

- ITG-Technical Committee 7.1 „Antennas“: Member
- Microwave and Radar Week (MRW) 2018, Poznań, Poland: Session Chair Member of the Technical Program Committee
- European Conference on Antennas and Propagation (EuCAP) 2018, London, UK: Member of the Technical Review Committee

AWARDS

Filippini, F.; Colone, F.; Cristallini, D.; Bournaka, G.:
2018 Premium Award for Best Paper in the journal „IET Radar, Sonar & Navigation“ for the publication „Experimental results of polarimetric detection schemes for DVB-T-based passive radar“

Grenz, O.:
„Second prize AFCEA Bonn e.V. Student award 2018“ for the master thesis: „Verlustoptimierung einer breitbandigen, doppelt polarisierten CBSP-Antenne im L-Band mit Betrachtung der Kreuzpolarisationsentkopplung, Fertigungsaspekten und Phased-Array Tauglichkeit“

Pohl, N.:
„Outstanding Young Engineer Award“ of the Microwave Theory and Techniques Society (MTT-S) of the Institute of Electrical and Electronics Engineers (IEEE)

Rama, J.:
Friedrich-Wilhelm-Gundlach-Preis, TU Berlin for the master thesis:„Theoretischen Synthese der SAR-Trajektorie eines 3D-Radarscanners im Millimeterwellenbereich“

Walterscheid, I; Wojaczek, P.; Cristallini, D.:
„Best Poster Award“ for „Challenges and first results of an airborne passive SAR experiment using a DVB-T transmitter“ at the 12th European Conference on Synthetic Aperture Radar (EUSAR), 4.-7. Juni 2018, Aachen

EVENTS

Conference Organisation

„Wachtberg-Forum“, 28.6.2018, Wachtberg

„Advisory Board Meeting“, 29.6.2017, Wachtberg

„International Summer School on Radar/SAR“, 13.-20.7.2018, Remagen

„ESA European Space Talks“, 15.11.2018, Wachtberg

EDA Workshop „AI and Cognitive Technologies for Radar, Comms and EW“, 3.-4.12.2018, Brussels, Belgium

Participation in fairs and Exhibitions

Fraunhofer FHR stand at the conference „Angewandte Forschung für Verteidigung und Sicherheit in Deutschland 2018“, 20.-22.2.2018, Bonn

Participation at the joint stand of Fraunhofer at the „Anuga FoodTec“, 20.-23.3.2018, Cologne

Participation at the joint stand of Fraunhofer at the „Hannover Messe“, 23.-27.4.2018, Hannover

Participation at the joint stand of Fraunhofer, of the space situational awareness center of the German Armed Forces, of the German Federal Ministry for Economic Affairs and Energy (BMWi) and of the BDLI Space Pavillion at the „ILA Berlin Air Show“, 25.-29.4.2018, Berlin

Fraunhofer FHR stand at the science night, 17.-18. Mai 2018, Bonn

Fraunhofer FHR-stand at the „Tag der Bundeswehr“, 9.6.2018, Mannheim

Fraunhofer FHR stand at the "International Radar Symposium" (IRS) 2018, 20.-22.6.2018, Bonn

Participation at the joint stand of Fraunhofer alliance traffic at the trade fair „SMM“, 4.-7. September 2018, Hamburg

Participation at the joint stand of Fraunhofer and TNO at the „European Microwave Week (EUMW)“ 2018 , 23.-28.9.2018, Madrid, Spain

Fraunhofer FHR stand at the „Security Essen“, 25.-28.9.2018, Essen

Participation at the joint stand of Fraunhofer alliance Space at the „International Astronautical Congress 2018“, 1.-5.10.2018, Bremen

Fraunhofer FHR stand at the„Bonding“, 16.10.2018, Bochum

Fraunhofer FHR stand at the „Technologietag“ of Fraunhofer alliance Vision 17.-18.10.2018, Jena

Fraunhofer FHR stand at the „International Symposium on Indirect Protection (ISIP)“, 15.-19.10.2018, Bad Reichenhall

Participation at the joint stand of Fraunhofer at the „Electronica“, 13.-16.11.2018, Munich

Fraunhofer FHR stand at the „Bonding“, 5.12.2018, Aachen

Fraunhofer FHR stand at the "Bonner Netzwerkabend", 12.12.2018, Bonn

ANNEX

LOCATIONS

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

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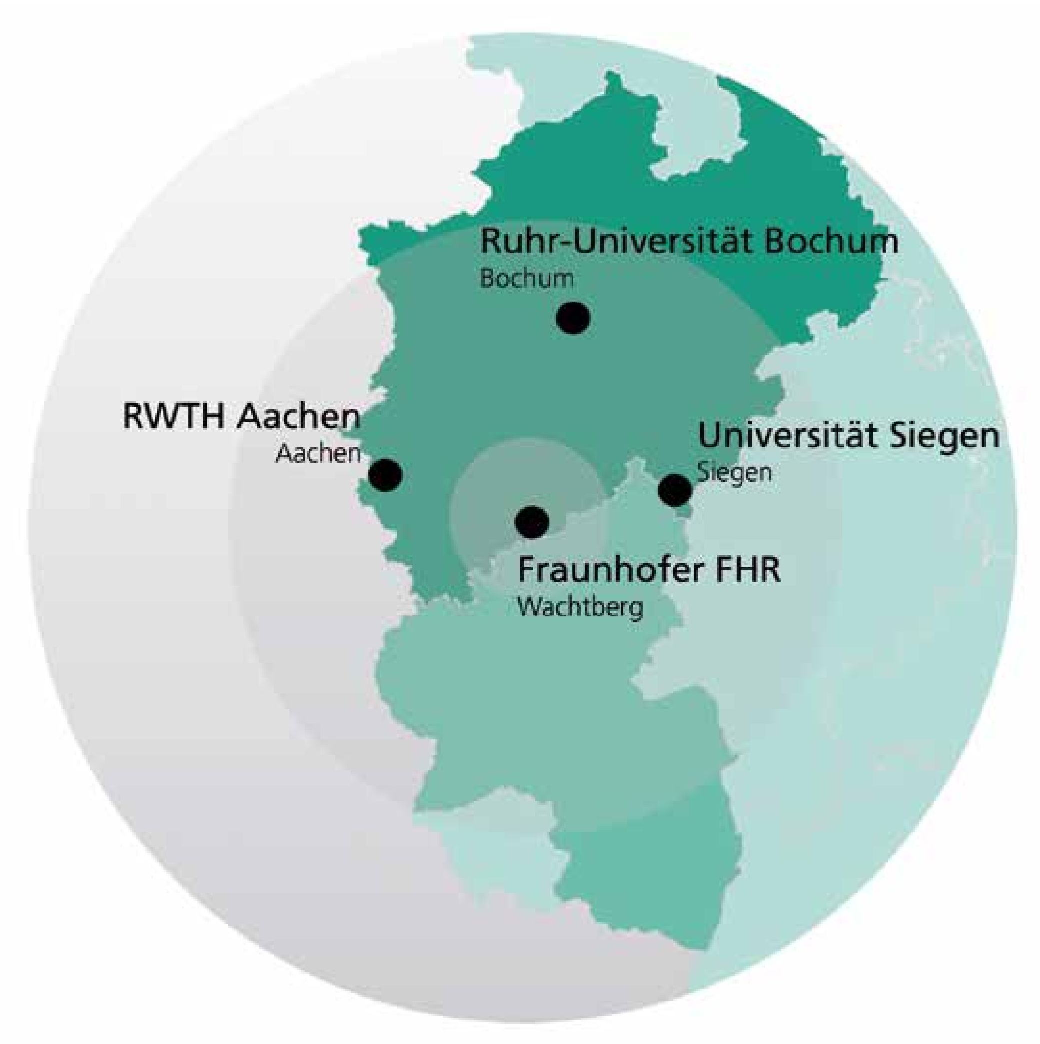

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Wachtberg, May 2019