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Who We Are:
A Research Network Advancing THz Technology

Where Innovation Meets Possibility

RUHR UNIVERSITÄT BOCHUM RUB | UNIVERSITÄT DUISBURG ESSEN | BERGISCHE UNIVERSITÄT WUPPERTAL | Fraunhofer IMS | Fraunhofer FHR

Who We Are

The Network for Excellence in Terahertz Research in North Rhine-Westphalia

At *terahertz.NRW*, we bring together the brightest minds in terahertz (THz) research from across North Rhine-Westphalia (NRW) and around the world. Our collaborative network is dedicated to unlocking the transformative potential of cutting-edge THz technology.

We are focused on advancing and developing innovative mobile applications across a variety of fields, including communication and localization, material characterization, medical technology, and environmental monitoring. Our goal is to elevate THz technology to a global stage – Made in NRW.

***terahertz.NRW* is a network comprised of Ruhr-Universität Bochum, Universität Duisburg-Essen, Bergische Universität Wuppertal, Fraunhofer IMS, and Fraunhofer FHR. It is proudly funded by the state of NRW.**

Communication & Localization

The joint vision of *terahertz.NRW* in the field of communication and localization is to investigate technologies and architectures that utilize the available frequency bands in the THz range with ultra-high bandwidth. In addition to the extremely high data rates that can be supported in the THz regime, the large bandwidth offers outstanding properties, such as finer distance/angle resolution, high-resolution images, localization in the cm/mm range, and low latency times for communication in 6G wireless networks. However, the shorter wavelengths and dense antenna placement lead to new challenges, as hardware distortions, such as phase errors and mutual coupling, have a much greater impact on system performance compared to lower frequencies.

terahertz.NRW is researching approaches to compensate for distortions in compact array devices and achieve the most energy-efficient operation and spectrally efficient modulation methods. In addition to using key hardware components such as reconfigurable intelligent meta-surfaces, modern machine learning techniques address hardware impairments and modeling uncertainties. In this context, efficient and fast data acquisition and processing are required and can be implemented with real-time-capable compressive sensing and other advanced signal processing methods. This also includes real-time compensation for non-linear and linear distortions.

Moreover, the availability of high bandwidths and advanced techniques for sharing the frequency spectrum enables 6G wireless networks to serve a large number of end devices simultaneously. To this end, the network is researching innovative approaches for radio access networks with directional THz antennas, access procedures, and integrated radar systems for localizing and (self-)synchronizing a large number of sensors and other end devices.

A UAV-mounted reconfigurable intelligent metasurface designed to enhance coverage and facilitate mobile access and sensing in disaster-stricken areas.

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Material Characterization

Imaging-based material characterization is one of the central research topics for the various network partners. An important pillar of this topic is the exploration of electronic and photonic technologies for hardware components in the THz range. The previous work of the Collaborative Research Center (SFB) MARIE plays a significant role in this context.

While reflective measurement methods that account for surface effects have been predominantly used so far, *terahertz.NRW* now aims to focus on transmissive geometries, compact concepts, transceivers, and algorithms for penetrating THz measurements of materials and volumetric bodies, thereby addressing highly relevant new aspects in the field of material characterization.

The goal of advancing from highly precise reflective imaging and material characterization at SFB MARIE to a transmissive tomographic approach forms a framework that integrates semiconductor technology, photonic signal generation, and signal pro ce s sing.

Transmissive tomographic imaging is currently used primarily in the medical field (ultrasound, X-ray CT, MRI) and in the security sector (X-ray CT). It is particularly valuable when materials need to be penetrated and internal material properties must be inferred. Millimeter-wave and THz tomography currently play a minor role in this context. However, when the use of ionizing X-ray radiation is unsuitable or when, unlike ultrasound, high-dynamic, contactless measurement is required, THz radiation offers an important alternative. This enables spectrally resolved imaging with manageable, integrated systems.

Relevant application fields include the imaging of model plants to study microstructures or nutrient transport in indoor farming modules, which creates strong connections to medical technology and environmental monitoring. Additional applications include 3D material analysis (e.g., 3D metamaterials) and new methods of non-destructive testing. The possibilities of THz tomography open up additional research fields, initiating new research projects, applications, and spin-offs from the network. The collaborative work of scientists and students forms the critical foundation for a sustainable and internationally visible research landscape in NRW.

Terahertz.NRW delivers comprehensive solutions from advanced component design and semiconductor development to nondestructive testing and precise measurements. With cutting-edge cleanrooms, absorber chambers, and state-of-the-art facilities, the network empowers innovation through its expert partners and infrastructure.

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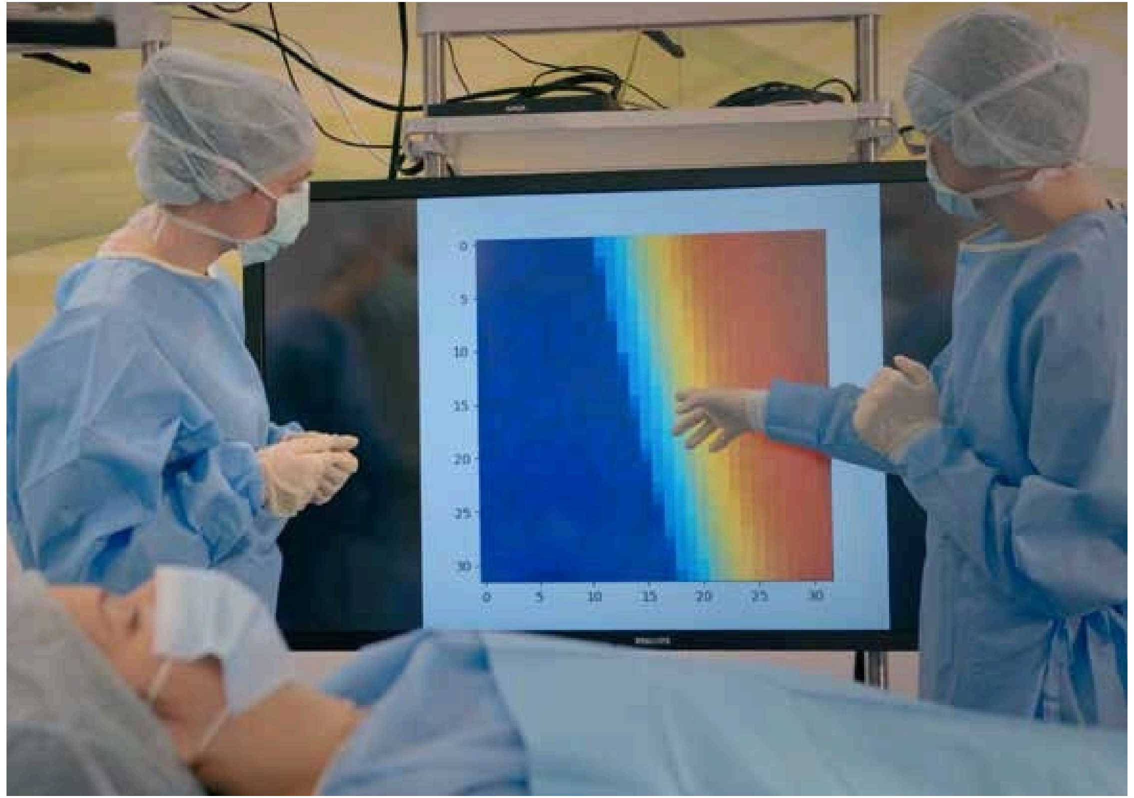
Medical Technology

At *terahertz.NRW*, we explore THz-based concepts that combine interdisciplinary expertise to develop innovative use cases in medical technology. Our research focuses on the development of THz applications for theranostics, point-of-care medicine, and advanced hospital systems. The primary areas of interest include Movement and Vital Diagnostics, Tissue Diagnostics, and Microfluidic Biosensors.

Movement and Vital Diagnostics: THz technology facilitates high-resolution measurements, even through textile materials, enabling non-contact monitoring of subtle movements on the body surface. By analyzing muscle movements, we aim to enhance the control mechanisms for exoskeletons and prosthetics. Furthermore, the unique properties of THz waves position this technology as a promising solution for overcoming the limitations of current vital signs monitoring methods. In this context, THz technology is being explored as a non-invasive and non-contact alternative to traditional methods for measuring vital parameters such as respiratory and heart rate.

Tissue Diagnostics: We are investigating the potential of THz imaging for mobile histopathology, aiming for rapid intraoperative assessment of tumor margins. This approach seeks to extend beyond the correlation of tissue properties with water content to include detailed analyses of morphological and physical characteristics. The development of a THz endoscope is a significant focus, aiming to provide real-time, high-resolution imaging capabilities.

Microfluidic Biosensors: Integrating THz sensor technology with microsystem technologies offers promising new applications in point-of-care diagnostics and neuroscience. Our current projects evaluate surface functionalizations and THz microsystems.



THz technology enhances surgical precision by offering high-resolution images of tissue and skin, surpassing traditional X-rays and avoiding ionizing radiation. As shown here, cell samples can be analyzed in real-time during surgery to ensure complete tumor removal, improving both diagnosis and treatment accuracy.

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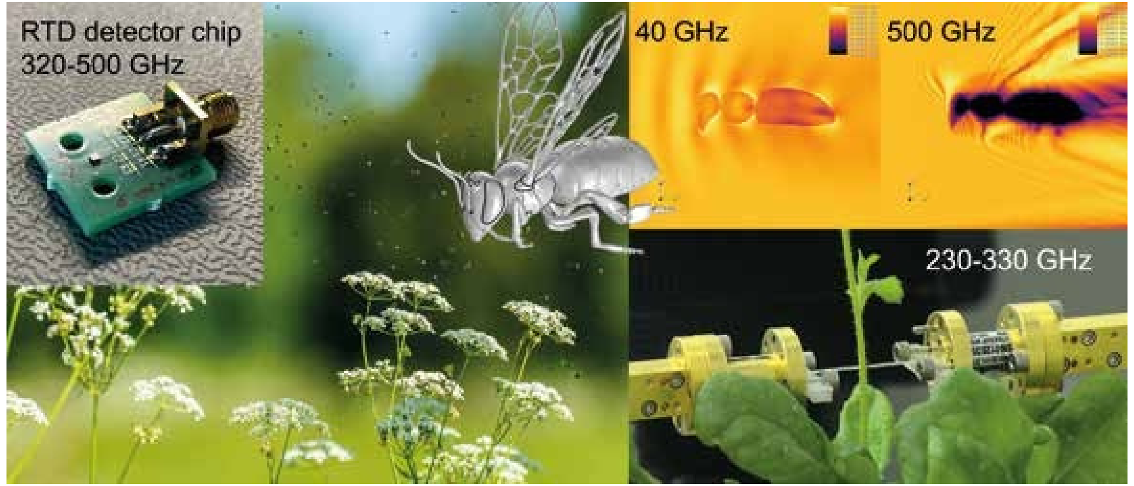
Environmental Monitoring

Current non-contact plant monitoring primarily assesses traits like water content, particularly for precision agriculture. *terahertz.NRW* introduces a holistic paradigm operating in the 0.2–5 THz range which includes miniaturized, mobile (bio-functionalized) THz sensors, agile THz radar imaging systems using Silicon-Germanium Bipolar Complementary Metal-Oxide Semiconductor (SiGe BiCMOS) technology, THz nearfield scanning, and non-linear THz tomography.

Terahertz.NRW develops localized plant monitoring systems that enable precise water and nutrient dosing using miniaturized, massively parallel THz sensor technology. These systems incorporate the world's smallest THz transceivers, made from Indium Phosphide (InP) Resonant Tunneling Diodes (RTD) and specialized InP transistors. Designed for rugged outdoor conditions, they are ultra-small, lightweight, energy-efficient, and equipped with networking capabilities for continuous off-grid deployment.

In addition to assessing plant status and stem transport with THz imaging, we aim to track root growth, pest damage, and heavy metal accumulation in real-time throughout the plant's life cycle. We also focus on plant interactions with small organisms like pollinators and pests. Our THz radar imaging allows 24/7 monitoring of pollinators' flight patterns and blossom visits by detecting their unique THz radar-cross-section (RCS). We examine how pests, such as aphids and mites, avoid heavy-metal contaminated plants using THz insect monitoring with enhanced sub-mm spatial resolution to track their movements.

We analyze the energy uptake in the European honey bee, a key pollinator and protected species, under 6G and THz radiation exposure, comparing it to International Commission on Non-Ionizing Radiation Protection (ICNIRP) safety limits using multiscale electromagnetic virtual dosimetry and digital twins of bees in calibrated THz experiments.



THz environmental monitoring involves extensive interdisciplinary collaboration among various research partners. This approach not only contributes to cutting-edge scientific developments but also shapes a unique identity for our research-oriented teaching.

The world's smallest electronic THz transceiver enables measurements to retrieve the plant's vital status, insect monitoring such as insect tracking, and electromagnetic exposure simulations using digital twins.

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