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6G SNS

TERahertz **Re**configur**A**ble **META**surfaces for Ultra-high-rate wireless communications

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Welcome to our 4th Newsletter!
TERRAMETA is approaching its end, and thus more and more milestones are achieved. The project has produced over 125 scientific publications, including 82 conference papers, 39 journal papers, and 8 magazine papers. It has also contributed to 9 patents and delivered 16 standardization contributions to IEEE and ETSI.

Read on to learn more about our scientific and dissemination activities and check the announcements at the end for upcoming events!

In this Newsletter:

- Non-Volatile RF Switching Technology for RISs
- Novel PCB Flip-Chip Processing for D-Band RIS
- AsGa On-Chip Metasurface
- Measurement-Based Channel Modeling
- Advancement towards 300 GHz
- CEA-LETI Innovation Day Demos
- TERRAMETA Dissemination Activities:
 - Past Workshops, Special Sessions, Expert Talks, and Tutorials
 - Announcement of Workshop "Bridging MIMO Signal Processing, Hardware Design, and Physically Consistent Modeling," IEEE ICASSP

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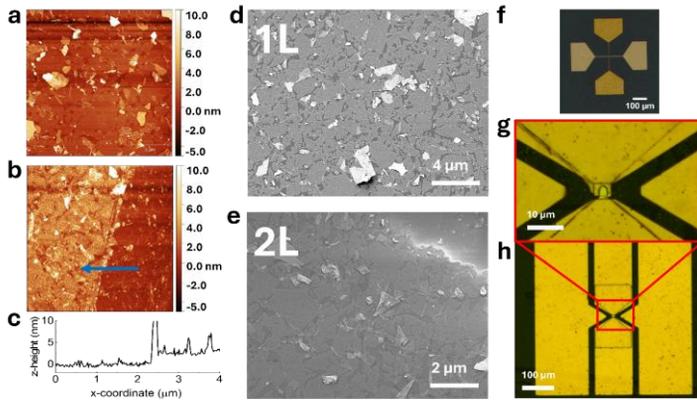


Non-Volatile RF Switching Technology for RISs

NOVA SCHOOL OF SCIENCE & TECHNOLOGY

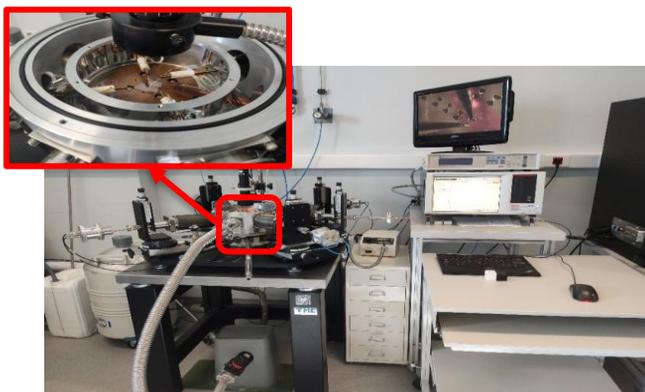
The development of RISs requires a reduction in power consumption which has become a key trend in sub-THz applications. A non-volatile switching mechanism means that continuous DC power is not required to maintain the switching state. In this context, the bilayer MoS₂ memristors have been fabricated using an electrochemically exfoliated nanosheet liquid-liquid assembly method.

The energy consumption of the set operation has been calculated as 330 pJ.

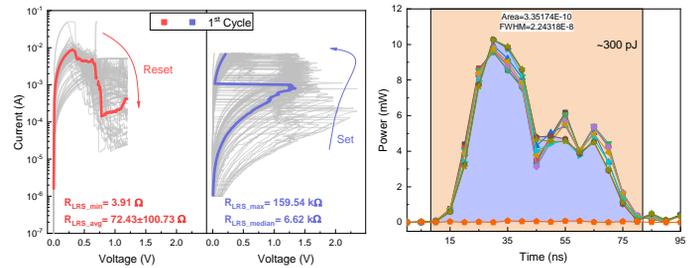


Morphological characteristics of the Ti/Au/MoS₂(2L)/Cr/Au memristor. a) AFM of MoS₂ Monolayer. b) AFM of MoS₂ Mono(1L) and Bilayers(2L) with step c) Profilometer measurement of the step from MoS₂ Mono(1L) to Bilayers(2L). d) & e) SEM of 1L and 2L MoS₂ films. f), g) & h) Micrographs of a crosspoint device and the memristor integrated with a Cu GSG CPW test fixture.

The RESET process was divided into two steps; firstly, applying a sweep from 0 V to 0.7 V with a compliance of 50 - 80 mA, then applying a sweep from 0.7 V to 1.2 V with a compliance of 1 - 5 mA. For Set process, a current-controlled sweep was performed from 1 μ A to 5 mA.

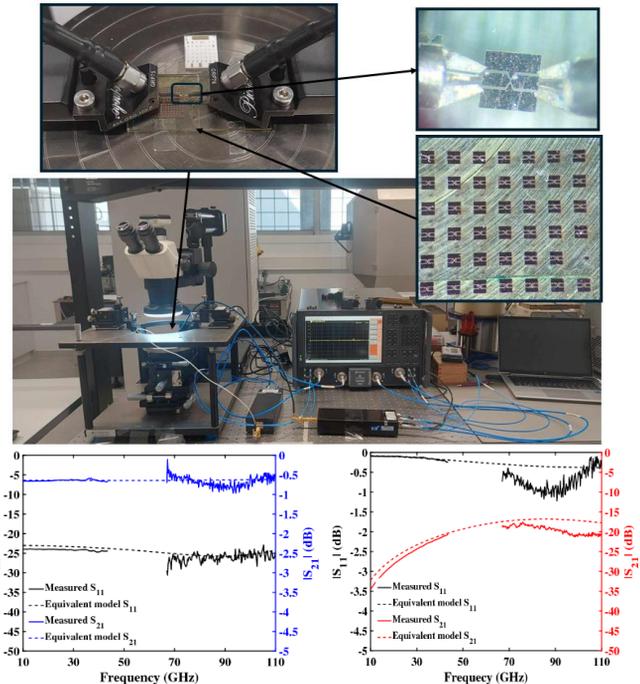


The DC electrical characterization setup



The IV characterization curves for RESET and SET process and the power consumption during Pulse SET.

The measured substantial S-parameters shows acceptable limits as a performance metric for an RF switch with an insertion loss <1 dB and an isolation > 18 dB over all frequencies up to 110 GHz. Moreover, the intrinsic electrical parameters are $R_{ON} = 6.8 \Omega$, $R_{OFF} = 14.1 K\Omega$ and $C_{OFF} = 4.3 fF$.



The experimental setup for the RF measurements and the S-parameters in both states LRS and HRS.

The proposed structure of the memristor fulfils the essential criteria for a memristor to be used as a high-performance RF switch. These metrics make this memristor a promising candidate for various applications in the 6G communications, such as RISs and RTAs.

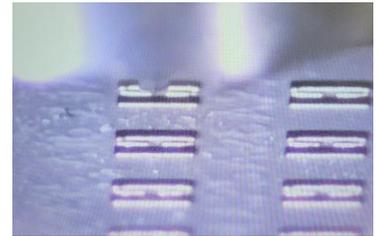
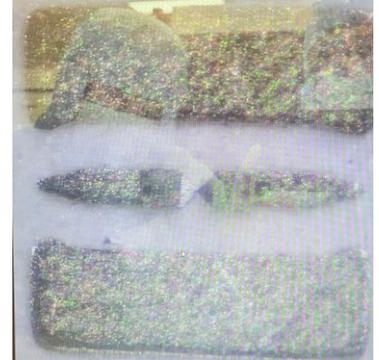
Novel PCB Flip-Chip Processing for D-Band RIS



Efforts are underway to overcome the limitations of conventional PCB flip-chip RIS assemblies. The standard approach cannot be scaled from RF to mmWave/sub-THz bands, as even the smallest flip-chippable dies are still too large—about the size of a $\lambda/2$ patch antenna at 140 GHz.

To address this, an innovative bonding strategy was evaluated using ultra-small diodes from project partner ACST. These diodes, only 8 μm thick with a tiny footprint, were bonded to gold pads with advanced equipment performing pick-up, alignment correction, and bonding in a single pass.

Initial trials used thermocompression bonding to avoid soldering, while a subsequent iteration employed ultrasonic bonding, enabling ultra-fast attachment in just a few seconds per diode.



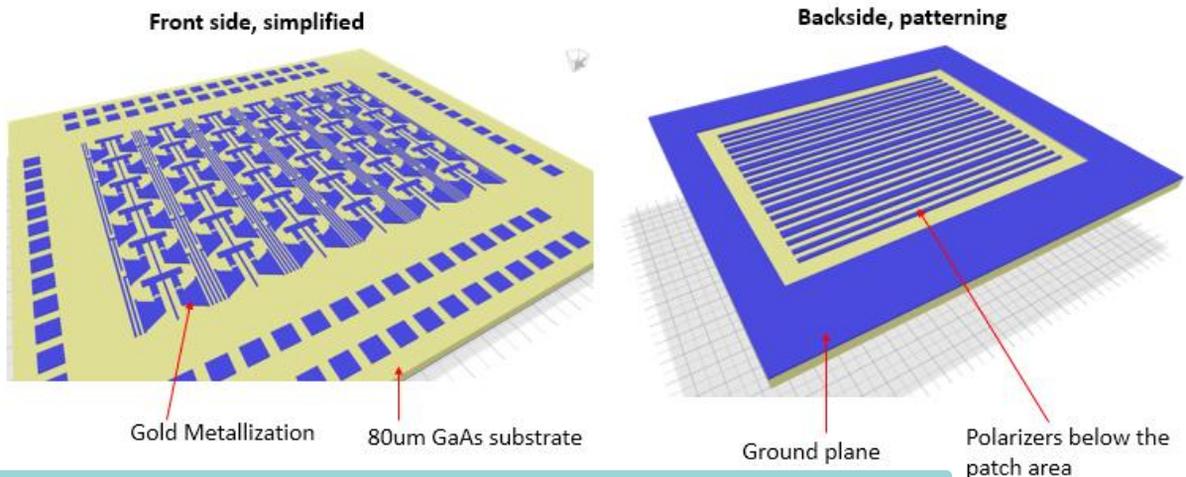
AsGa on-chip Metasurface



Another approach to RIS miniaturization—addressing both the integration of phase-controlling switches within the antenna patch and the tight process tolerances for metal etching—is to use GaAs diodes on a non-intentionally doped (n-i-d) GaAs substrate, with interconnects patterned by lift-off. In short, the concept is to employ III-V technology on 6-inch wafers, integrating switch and antenna array on the same chip.

The key advantage is avoiding the gold etching step of PCB fabrication, where achieving better than 5–10 μm precision is difficult. With lift-off in a cleanroom, tolerances down to tens of nanometers are standard, enabling the accuracy needed for antenna patches—arguably one of the strongest arguments for integrated technologies.

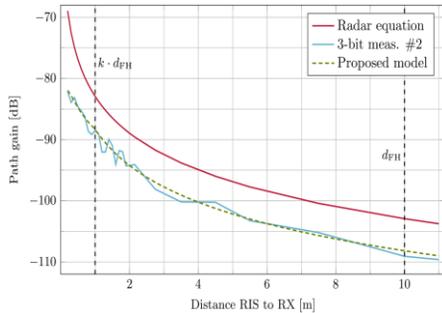
As proof of concept, a 4 × 4 mm² tile with patch antennas on an n-i-d GaAs substrate and integrated GaAs diodes was designed for a 140-GHz transmit array. The drawback: production stretches from weeks to months. So stay tuned for results—but don't hold your breath!



Measurement-Based Channel Modeling

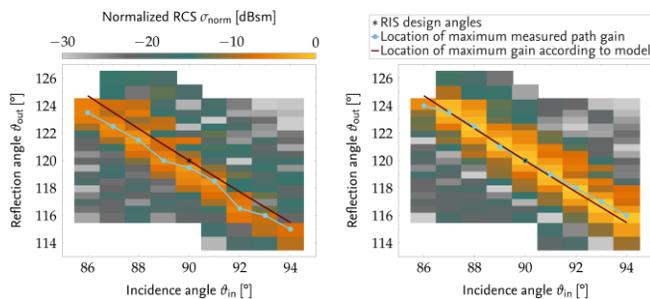
Heuristic RIS Modeling

- Building on previous measurements, a path gain model based on the bistatic radar equation that accounts for near field effects was derived.



Radar equation, measurement, and proposed model.

- A measurement campaign examining the angular behavior of the RIS validated the proposed model predicting the direction of the RIS main reflection as a function of the RIS phase configuration, the design frequency, the actual angle of incidence, and the actual operating frequency (beam squint).

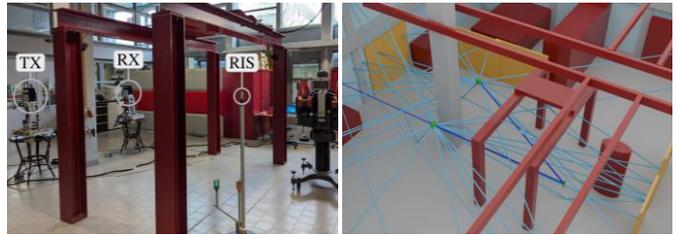


Heatmaps of measured RCS over angles.

- Exploiting the measurement results, an energy compliant two-beam RIS radar cross section (RCS) model with additive Gaussians as lobes for the main and the specular reflection and a cosine-tapered base level as approximation for the sidelobes was developed and implemented into a ray tracer.

Channel Modeling with Validated Simulation Environment

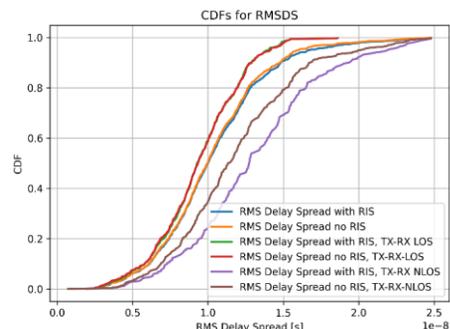
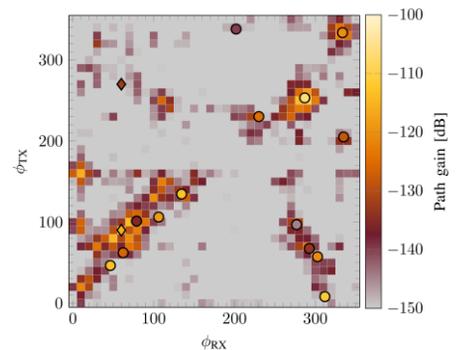
- A measurement campaign involving a TERRAMETA passive RIS prototype at 300 GHz in a realistic industrial environment performing double-directional azimuth angular sweeps was conducted.



Left: Measurement environment. Right: Corresponding simulation environment with rays.

- A great fit between measured and simulated angular profile validated the simulation environment such that further simulations were performed to obtain statistical insights into the effect of RIS in the propagation channel.

Angular profiles of measurement (heatmap) and simulation (overlaid markers, RIS paths as diamonds).

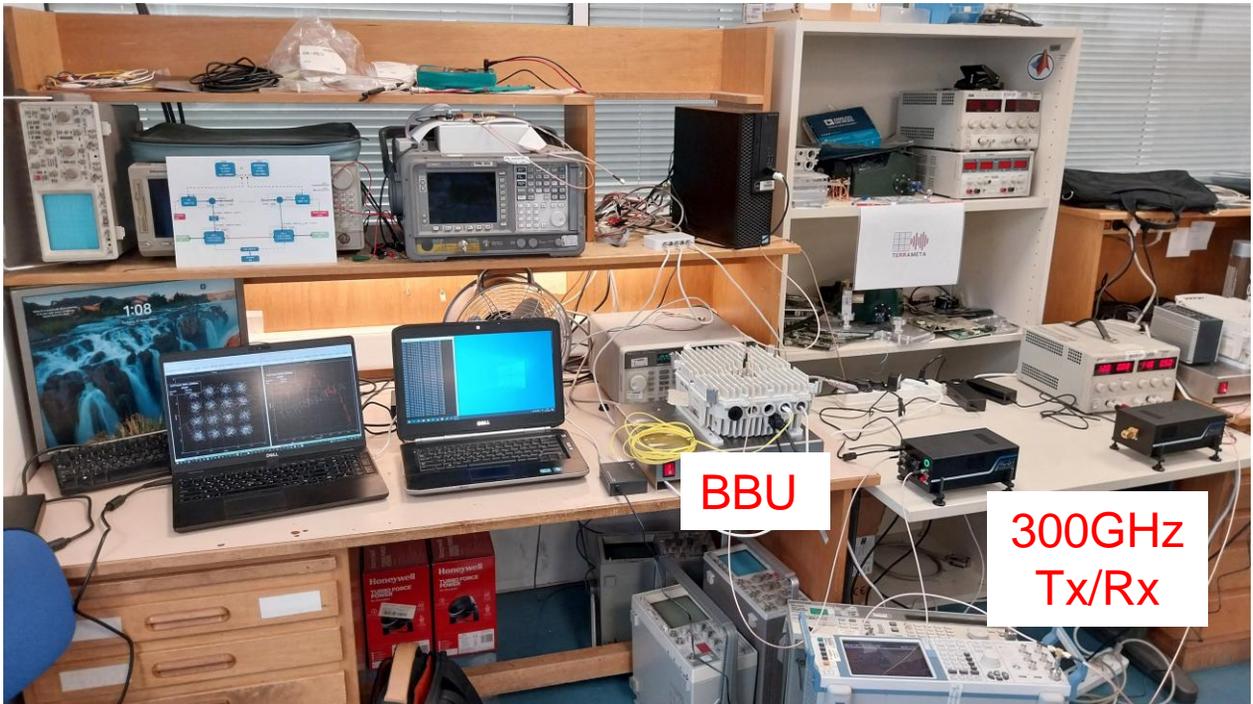


Exemplary result: CDFs show that RIS only influences the RMSDS of the propagation channel in cases of NLOS between TX and RX.

300 GHz Link Testing



- WP6 has successfully expanded its validation efforts into the 300 GHz frequency range, achieving significant milestones that pave the way for future multi-hundred GHz communication systems. In recent tests, the consortium successfully integrated ACST's 300 GHz transceiver modules with ICOM's Baseband Unit to achieve 5 Gbps data rate using 16QAM modulation at 30 cm distance.
- This successful demonstration represents a critical step toward practical implementation of THz communications for 6G networks. While challenges remain regarding range extension and environmental robustness, these results confirm the viability of multi-hundred GHz frequencies for ultra-high-rate wireless applications. These results show TERRAMETA continuing its foundational efforts in the 300 GHz band.



300GHz Link Testing with BBU and 300GHz Tx/RX.

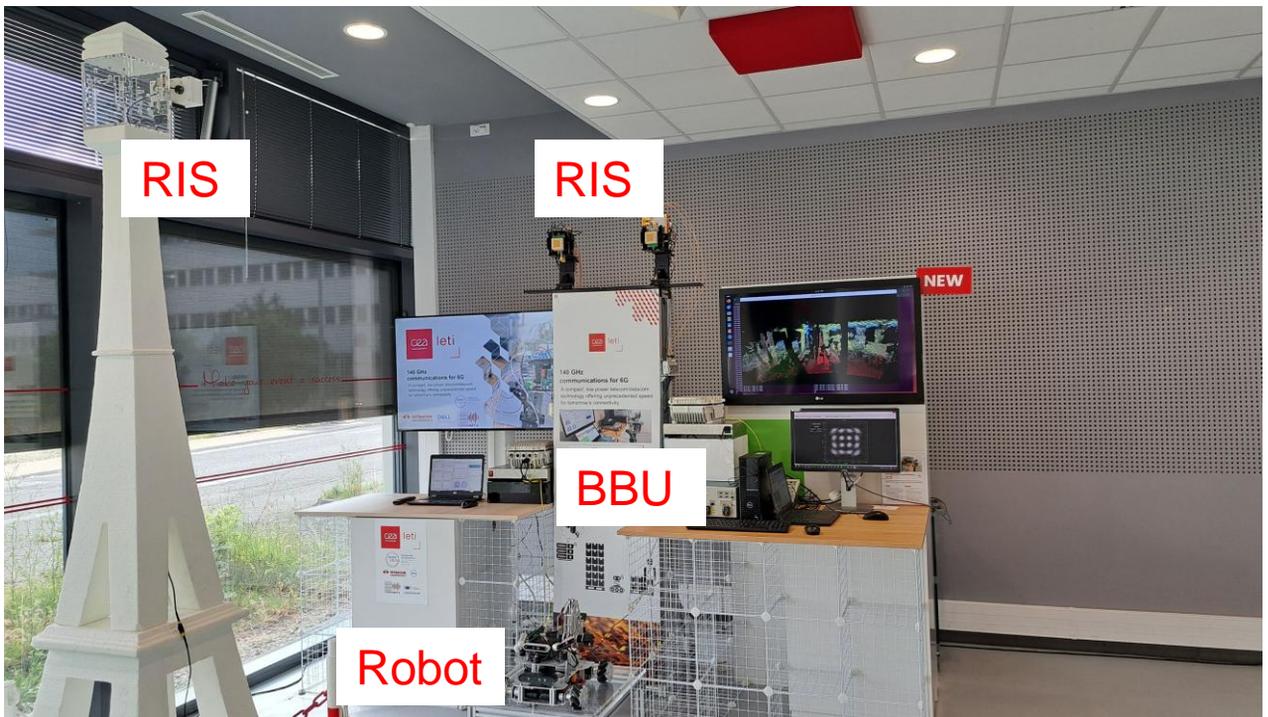
- First tests with an AWG as a BB unit were performed at CEA-Leti.
 - Four BB channels upconverted to IF with mixer at Tx 13cm using 20 dBi horn antennas at the 300 GHz heads.
 - 16-QAM and 64-QAM successfully transmitted and received with over 9 GHz of Bandwidth centered at 305 GHz, demonstrating up to 42.24 Gb/s and BER 10^{-2}.
- ### 300GHz RIS Development
- The TERRAMETA project has also fabricated two 300GHz RIS designs:
 - A 300 GHz passive RIS design developed by IT.
 - A transmissive RIS operating at 300 GHz developed by CEA-Leti.
 - These designs will soon be tested in conjunction with the BBU and use cases for fully operational 300GHz RIS wireless links in WP6.

CEA-LETI Innovation Days Demo



- In June 2025, the TERRAMETA consortium successfully demonstrated a significant advancement of our industrial robot use case at the CEA-Leti Innovation Days, building upon our previous demonstration at the European Microwave Week (EuMW) 2024. This updated demonstration marks a major milestone in THz wireless communications for industrial applications.

- The demonstration featured our industrial robot equipped with high-resolution RGB-depth cameras streaming 3D sensor data to an edge server via a D-band THz link. The system employed an active RIS repeater configuration to demonstrate the concept of navigating signals around physical obstructions, showcasing how THz communications can overcome line-of-sight limitations in industrial environments.



TERRAMETA Demo at CEA-Leti Innovation Days

Key Improvements Over Previous Demo:

- 5 Gbps sustained throughput** achieved with stable 16QAM operation (vs. 1.4 Gbps at EuMW).
- 2.5 meter total link distance** with active RIS repeater configuration (vs. 2 meters at EuMW).
- Enhanced reliability** with reduced frame error rates and less link drop-outs.

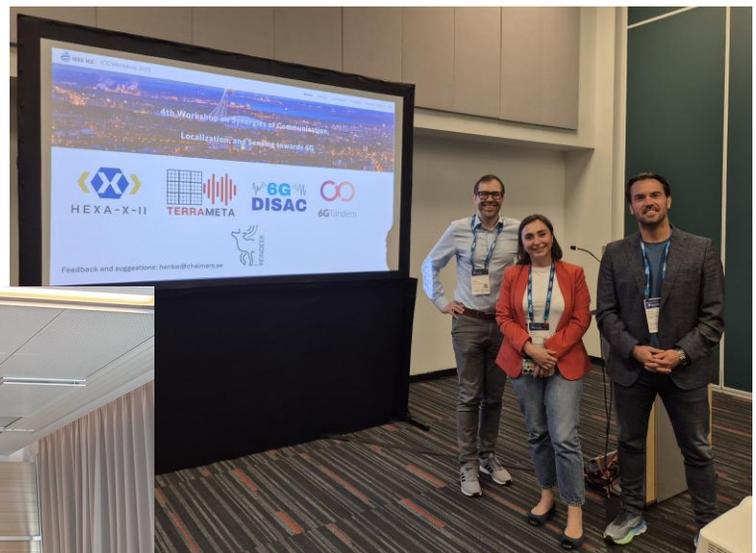
- This achievement demonstrates THz communications' viability for next-generation use cases. The ability to maintain multi-gigabit throughput with sub-ms latency in real world tests addresses critical requirements for real-time sensor feedback and control for mobile robotics. The demonstration shows THz RIS technology moving beyond theoretical promise to practical implementation, positioning TERRAMETA at the forefront of 6G THz communications development.

Dissemination Activities

Workshops

- “Sub-THz Reconfigurable Intelligent Surfaces, RF Front-Ends, and Channels for 6G Networks”, EuCAP 2025, Stockholm, Sweden, 30 March–4 April 2025.
- “5th Workshop on Integrated, Intelligent and Ubiquitous Connectivity for 6G and Beyond” IEEE PIMRC, Istanbul, Turkey, 1–4 September 2025.
- “3rd Workshop on Near-Field Communications, Localization, and Sensing” IEEE ICC, Montreal, Canada, 8–12 June 2025.
- “4th Workshop on Synergies of Communication, Localization, and Sensing towards 6G” IEEE ICC, Montreal, Canada, 8–12 June 2025.
- “Integrated Sensing and Communications Initiative on the European Research Framework”, Joint EuCNC & 6G Summit, Poznan, Poland, 3–6 June 2025.

Picture from “4th Workshop on Synergies of Communication, Localization, and Sensing towards 6G”, IEEE ECC 2025.



Picture from “Sub-THz Reconfigurable Intelligent Surfaces, RF Front-Ends, and Channels for 6G Networks”, EuCAP 2025.

Up-to-date scientific contributions:

- 129 journal/conference/magazine publications and 78 dissemination activities available on the website



<https://terrameta-project.eu>

Dissemination Activities

Special Sessions

- “Towards real-world deployment of THz and RIS for Industry 5.0: From Theory to Practice”, IEEE CSCN 2025, Bologna, Italy, 15–17 September 2025.
- “Signal Processing for XL MIMO and Holographic MIMO”, 33rd EUSIPCO, Palermo, Italy, 8–12 September 2025.
- “Machine Learning for Wireless Localization and Sensing”, IEEE SPAWC, Surrey, UK, 7–12 July 2025.
- “Extremely Large or Distributed Antenna Systems in Near-Field Environments”, EuCAP, Stockholm, Sweden, 30 March–4 April 2025.



Picture from “Extremely Large or Distributed Antenna Systems in Near-Field Environments”, EuCAP 2025.

Picture from "Integrated Sensing and Communications Initiative on the European Research Framework", Joint EuCNC & 6G Summit 2025.



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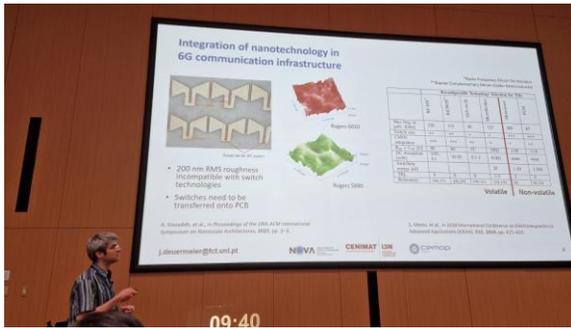
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Dissemination Activities

TERRAMETA at Neuronics Japan!

NOVA team was honored to be invited as speakers and evaluation members at *Neuronics Japan 2025*, where we showcased cutting-edge developments in memristor technology. We presented new functionalities of memristors for Reconfigurable Intelligent Surfaces (RIS), highlighting their strong performance and exciting promise for future intelligent communication platforms.



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Dissemination Activities

Expert Talks

- “Recent Advances in Multifunctional Programmable Metasurfaces and Their Beyond 5G Applications”, IEEE Student Branch IIT, Patna, India, 21 November 2025.
- “On the Optimization of BD-RIS-Empowered MIMO Wireless Systems”, BD-RIS Webinar Series, Online, 12 November 2025.
- “XL MIMO Systems: From ISAC Boosting to Over-the-Air Inference”, EURASIP Webinar, Online, 24 September 2025.
- “Integrated Sensing and Communications: The Promising Roles of Full-Duplex MIMO and Reconfigurable Intelligent Surfaces”, 11th European Future of Wireless Workshop, Huawei Technologies Sweden AB, Stockholm, Sweden, 16 September 2025.
- “XL MIMO for Integrated Sensing, Communications, and Over-the-Air Computing”, Lake Como School of Advanced Studies, Italy, 7 July 2025.
- “Channel Characterization and Beamforming Design for Metasurfaces at THz Frequencies”, Joint SNS Workshop TIMES, 6G-SHINE, and TERRAMETA, 26 May 2025.

Tutorials

- “Full-Duplex MIMO for Simultaneous Communications and Sensing”
IEEE Radar Conference, Krakow, Poland, 4–10 October 2025.
- “Distributed Integrated Sensing and Communications: Foundations, Opportunities, and Challenges”, IEEE ICC, Montreal, Canada, 8–12 June 2025.

Announcements

- “Bridging MIMO Signal Processing, Hardware Design, and Physically Consistent Modeling”, IEEE ICASSP, Barcelona, Spain, 4–8 May 2026.

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