Newsletter #2

TERRAMETA

Co-funded by the European Union

6G SNS

TERahertz ReconfigurAble METAsurfaces for Ultra-high-rate wireless communications

This project has received funding from Horizon Europe, the European Union's Framework Programme for Research and Innovation, under grant agreement 101097101. The project is supported by 6G SNS and its members (including top-up funding by UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee)

- ❑ Novel hardware development for 6G THz communications.
- ❑ Design of THz-tailored network architectures based on realistic models.
- ❑ Development of signal processing techniques for THz communications, localization, sensing, and their integration with state-of-the-art multi-functional RISs and dynamic metasurface antennas.
- ❑ Demonstration of two THz networking use cases via the project's fabricated RISs and transceivers: an industrial edge environment and an outdoor telecom scenario.
- ❑ Influence 6G and THz communications standardization and regulation.

Project Overview:

- **Bologna joint Workshop with TIMES 6G and 6G-SHINE**
- **TERRAMETA at EuCAP 2024**
- **CEA/ICOM Demonstrator**
- **Channel sounding campaign at TUBS**
- **RF memristor work progress**
- **Microfluidic-based sub-THz RIS**
- **Simultaneous reflecting and sensing RIS**
- **Signal processing for THz multi-functional RISs**

Announcements:

- **SNS ISAC Workshop**
- **B-MRS memristor symposium**
- **IEEE ICC 2024 Workshops**

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https://terrameta-project.eu/

INESCTEC
BT
National and Kapodistrian University of Athens
Established in 1827
UNIVERSITY OF OULU
UNIVERSITY OF LUXEMBOURG
INTRACOM TELECOM
Technische Universität Braunschweig
CST THINK AHEAD
University of Hertfordshire UH
DELL Technologies
instituto de telecomunicações
NOVA SCHOOL OF SCIENCE & TECHNOLOGY
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Bologna joint Workshop with TIMES and 6G-SHINE

TERRAMETA, TIMES 6G, and 6G-SHINE projects came together for a joint SNS Workshop, held in synergy with the Fondazione RESTART (IN project) in Bologna, Italy, on February 1st. This opportunity was sparked by the "RESTART Plenary Dissemination Workshop" (January 30-31), which aimed to showcase the Italian RESTART project: “Research and innovation on future Telecommunications systems and networks, to make Italy more smart.”

During the workshop, Luís Pessoa presented the latest advancements in the TERRAMETA project (“Overview of the TERRAMETA Project"). Further insights were shared through presentations by J. Vásquez Peralvo ("Scalability Analysis of RIS in Terahertz"), B. K. Jung ("RIS Application on THz X-haul Links from Simulation to Measurement"), and A. Clemente (“Advanced transceiver-antenna co-integration techniques at mmWave and sub-THz: recent achievements and future challenges”).

This productive gathering fostered new collaborations and identified opportunities for joint ventures in the field of high-frequency (THz) wireless communication.

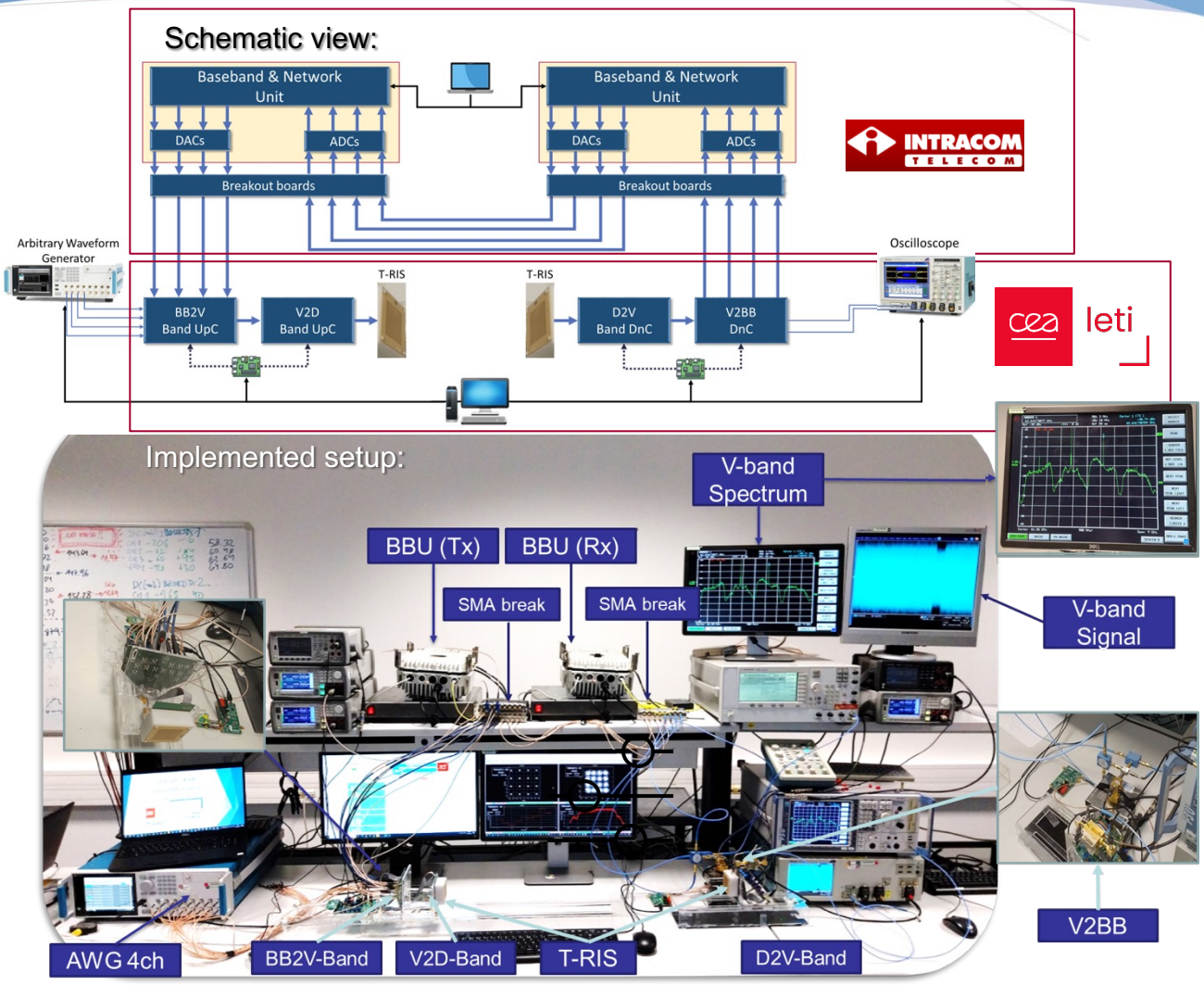
TERRAMETA at EuCAP 2024

The TERRAMETA consortium made a lasting impression at the 18th European Conference on Antennas and Propagation (EuCAP 2024) held from 17-22 March in Glasgow, Scotland. The team's significant presence showed the innovative work being carried out on the project.

The TERRAMETA presentations covered a wide range of topics, all focused on pushing the boundaries in Terahertz (THz) technology. Titles and presenters included:

- "Automatic Planning Algorithm of 300 GHz Backhaul Links Using Mesh Topology" (Bo Kum Jung)
- "Performance Analysis of THz Backhaul Links Assisted by Reconfigurable Intelligent Surfaces" (Bo Kum Jung)
- "1-Bit SubTHz RIS with Planar Tightly Coupled Dipoles: Beam Shaping and Prototypes" (Dr. Qi Luo)
- "Adaptive Polynomial Chaos Expansion for Uncertainty Quantification of SubTHz Horn Antennas with Flat-Top Radiation Patterns" (Dr. Yihan Ma)
- "Irregular Subarray with Gathered Elements for Sidelobe Suppression" (Dr. Yihan Ma)
- "Improved Performance of a 1-Bit RIS by Using Two Switches per Bit Implementation" (Fábio Cardoso)
- "Multibeam Antenna for Wide-Angle 95-Beam Coverage at Ka-Band Using a Multifocal Transmit-Array" (Sérgio Matos)
- "Novel Risley Prism Design Approach with Improved Side Lobe Levels Using Multi-Layer Transmit-Arrays" (Sérgio Matos)
- "Reconfigurable Intelligent Surfaces for THz: Signal Processing and Hardware Design Challenges" (Sérgio Matos)
- "Sub-THz Spatially Modulated Beam Splitting Reflectors for Potential RIS Implementations" (poster, Tung Phan)

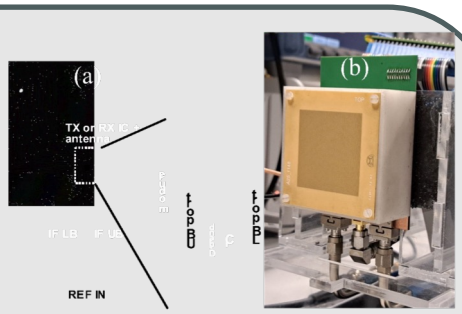
CEA/ICOM Demonstrator

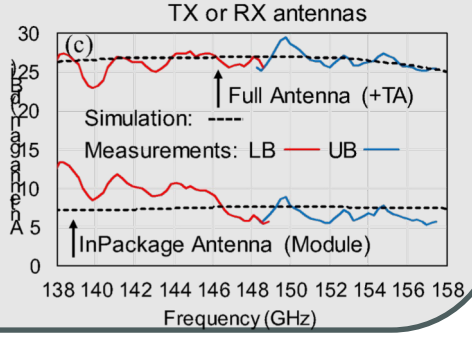


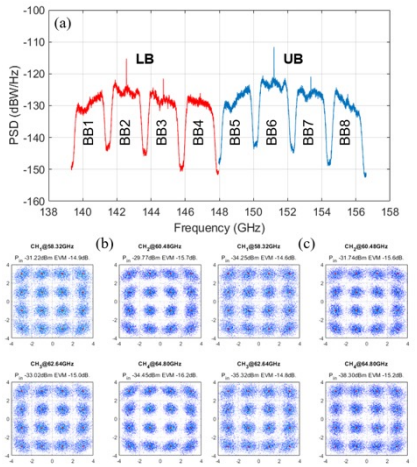
(a) Receiver module and details of in-package antenna.

(b) Transmit array mounted over the in-package antenna module.

(c) Measured and simulated boresight antenna gain of the in-package focal-plane antenna and the overall system with the transmit array.





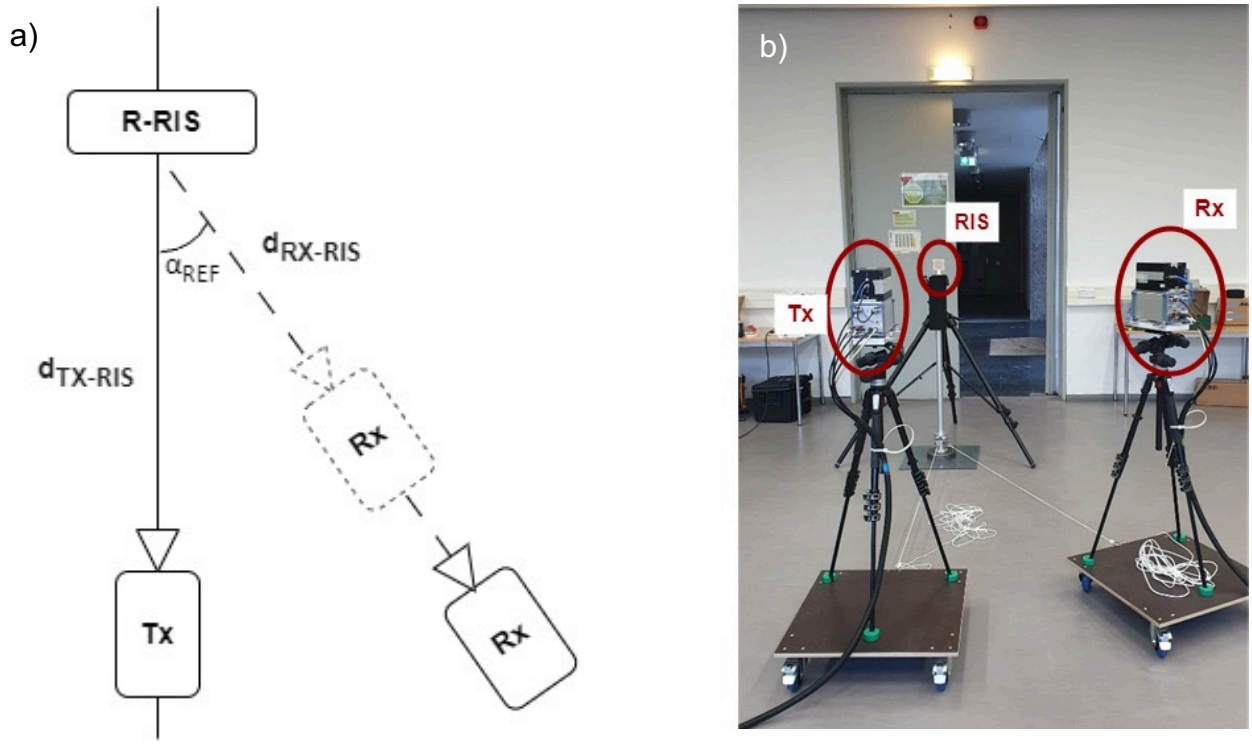


(a) Received signals at both LB and UB IF outputs against their corresponding D-band frequencies. Demodulated 16-QAM constellations for (b) the four LB channels, and (c) the four UB channels.

Channel sounding campaign - TUBS

Initial measurements of 300 GHz channel including RIS

- The first approach to 300 GHz Reconfigurable Intelligent Surfaces (RIS) channel measurements was carried out jointly by the TERAMETA and TIMES projects over a period of two weeks from 04 March 2024 to 15 March 2024 at Technische Universität Braunschweig.
- During the two weeks, a total of three different measurement scenarios were focused on understanding the characteristics of RIS and the propagation channel including RIS.
- Three different types of passive reflective RIS were designed by TERRAMETA and accordingly manufactured for 1 bit, 2 bits and 3 bits, each differing in their potential for reconfiguration and symmetry of radiation pattern. These reflective RIS have a shape of 5cm x 5cm (100 by 100 arrays) and their operation are optimized for a fixed angle of 0° for the angle of incidence and 30° for the angle of reflection. In addition, a transmissive RIS with the gain of 37 dBi was available for the measurement.



Measurement scenario a) schematic view from above b) photo of the measurement scenario

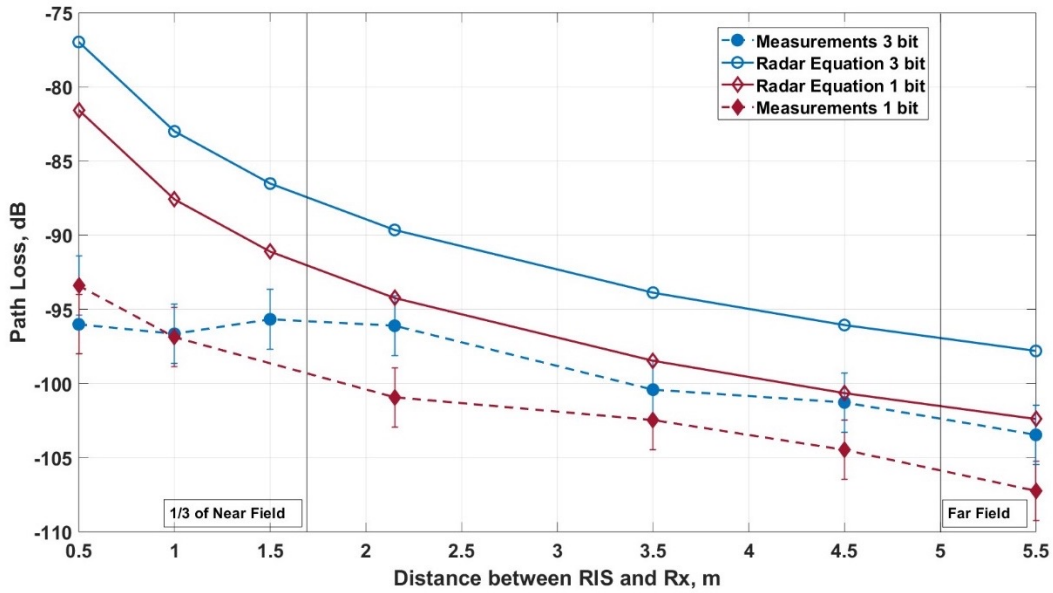
One of the measurement scenarios was to understand the near/far field propagation properties by moving receiver (Rx) towards to RIS while maintaining the position of a transmitter (Tx) and RIS unchanged. Distance between Tx and RIS was fixed, d_{TX-RIS} = 2.15 m. The distance between Rx and RIS (d_{RIS-RX}) was changed from 0.5 m to 5.5 m. The incident angle (α_{INC}) was fixed at 0°. The reflection angle (α_{REF}) had two values 30° and -30°.

Channel sounding campaign - TUBS

To compare the measured value with the simulation, the radar equation is used to calculate the path loss (PL).

$$P_{RX} = \frac{P_{TX} \cdot G_{TX} \cdot G_{RX} \cdot \sigma}{(4\pi)^3 \cdot d_{TX-RIS}^2 \cdot d_{RIS-RX}^2} \qquad (1)$$

Where PRX – received power; PTX – transmitted power; GTX, GRX – Tx and Rx antennas gain; σ – radar cross section, obtained from RIS simulated radiation pattern; dTX-RIS, dRIS-RX – distances between Tx and RIS and RIS and Rx respectively. Then, PL was calculated by subtracting the transmitted power and antenna gains from the received power.
A comparison between measured and expected PL values for both 1 bit and 3 bits RIS at αREF = 30° is presented in the figure below.



Comparison of PL values calculated by radar equation and measured data, α_{REF} = 30°

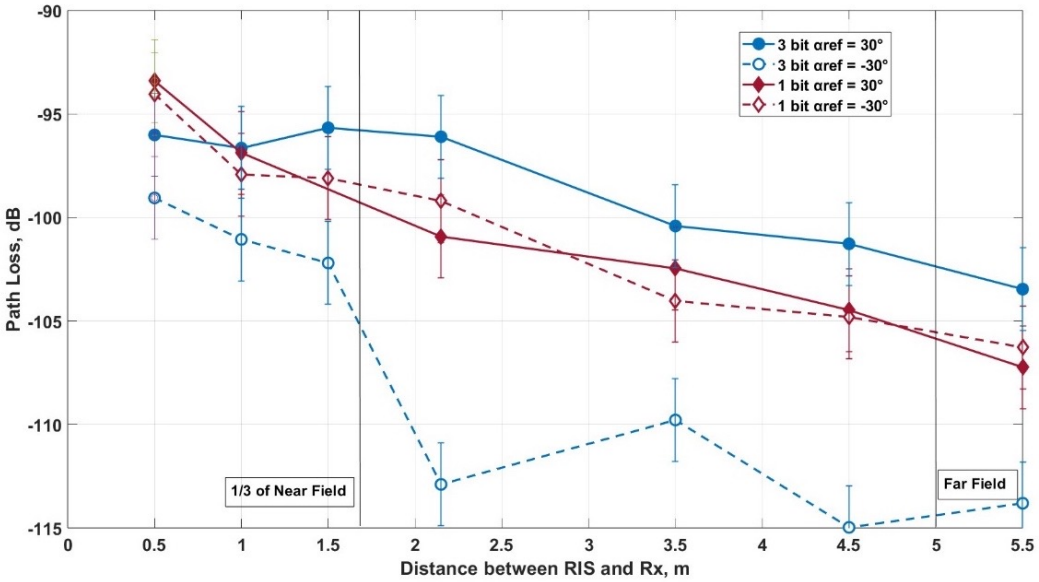
It can be observed that starting from a distance of 2 m, the difference between the expected and measured curves is approximately the same for all points of the 1 bit and 3 bits RIS, respectively. The difference between calculated and measured data is presented in the table. A significant difference between calculated and measured values at distances less than 2 m may correspond to the 'one-third of the near-field' rule, which determinates the transitional region between the reactive and radiative fields. Nevertheless, further in-depth investigation is needed to assess the impact of this region. It is also worth mentioning that the measurement equipment error is approximately 2 dB.

d_{RIS-RX}, m	PL_{CALC} - PL_{MEAS}, dB	
	1 bit	3 bits
0.5	11.8	19
1	9.3	13.7
1.5	–*	9.2
2.15	6.7	6.5
3.5	3.9	6.5
4.5	3.8	5.2
5.5	4.8	5.7

*This point should be re-measured.

Channel sounding campaign - TUBS

The plot in the figure below shows a comparison of measurement results with reflective angles of 30° and -30° for both 1 bit and 3 bits RIS. It can be observed that the measured values with a reflective angle of 30° and -30° for the 1-bit RIS are the same, within the equipment error, which aligns well with the simulated radiation pattern. Differences between measured values with reflective angles of 30° and -30° for the 3 bits RIS are presented in the table below.
It can be noted that at distances less than 2 m, there is again a noticeable difference between expected values based on the simulated radiation pattern and measured data.



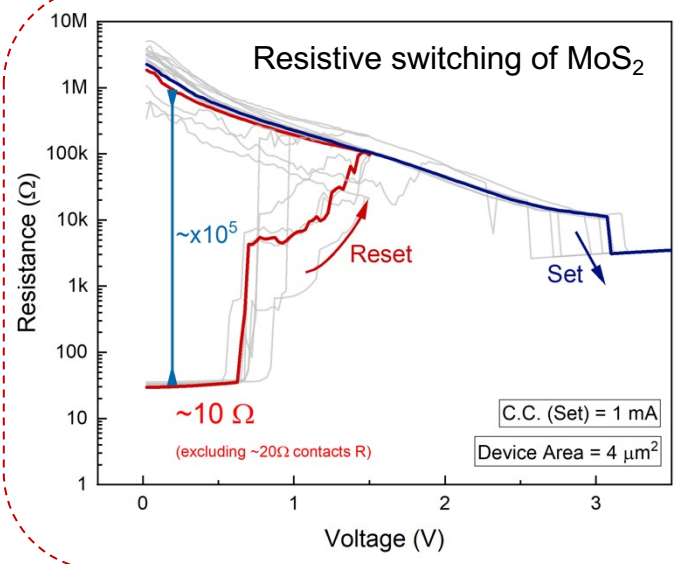
Comparison of measured PL for α_{REF} = 30° and α_{REF} = -30°

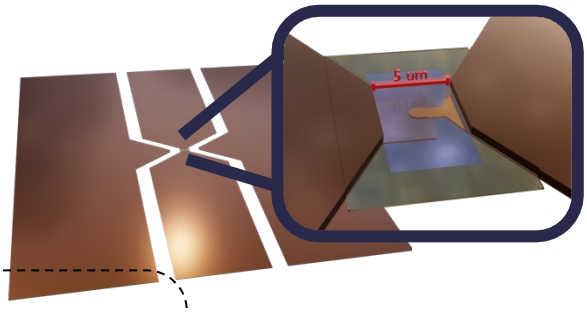
The initial channel measurements of 300 GHz reflecting RIS indicate that the use of the radar equation yields good results when compared with measurement data, with an offset ranging from 4 to 6 dB for distances greater than 2 m. However, results for distances less than one-third of the near field require further investigating the influence of this region.

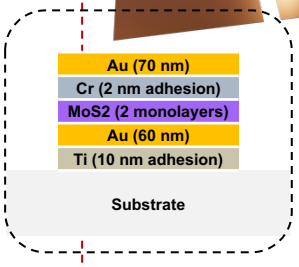
For more detailed information on the measurement of the channel, please refer to the TERRAMETA deliverable D5.1.

d_{RIS-RX}, m	$PL_{30°} - PL_{-30°}$, dB
0.5	-3.0449
1	-4.411
1.5	-6.5321
2.15	-16.793
3.5	-9.3722
4.5	-13.6987
5.5	-10.343

RF memristor-based devices

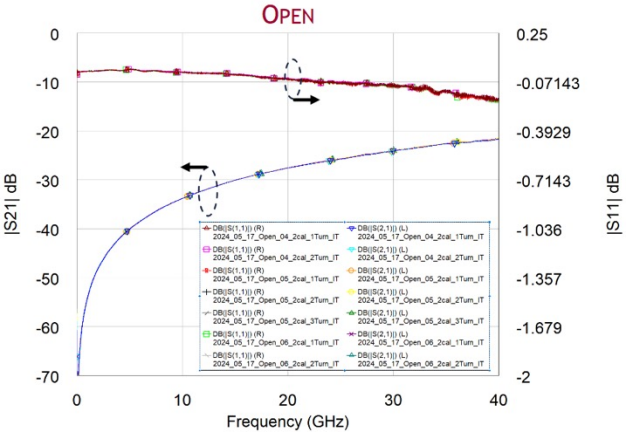


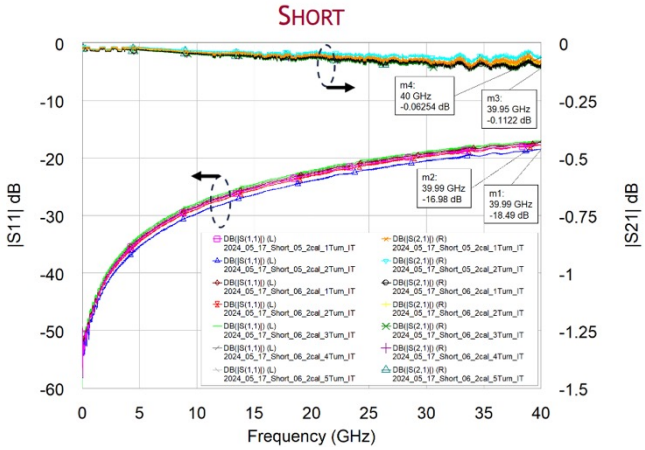


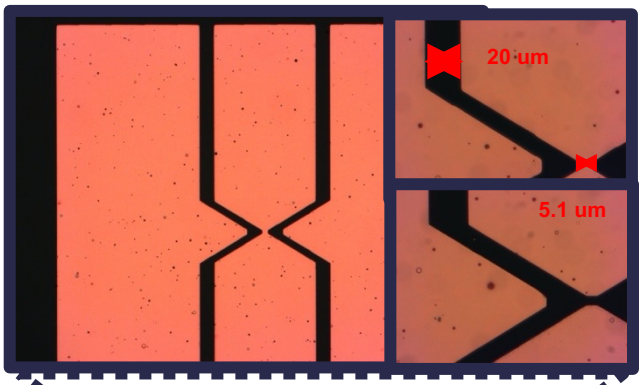


500nm thick **Copper** test fixture deposited by Electron-beam evaporation and patterned via Lift-Off

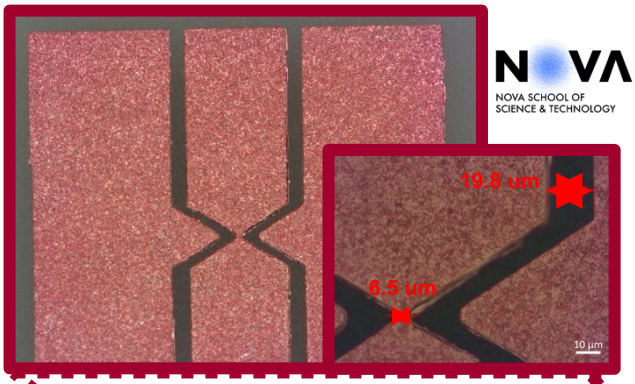
Measurements of short and open structures.
Each open is measured 2-5 times (1Turn, 2Turn, 3Turn, 4Turn , 5Turn).







Fused Silica substrates

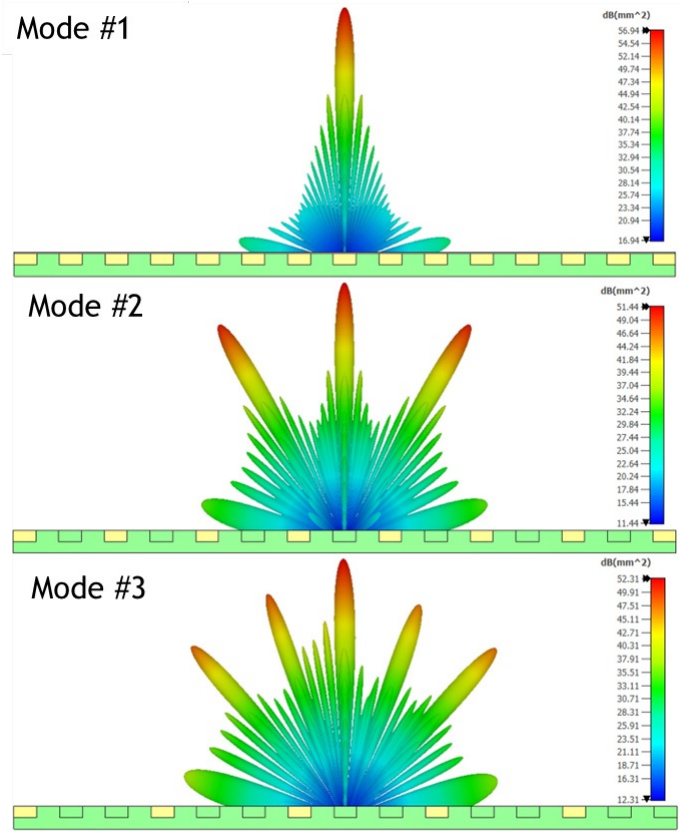


Panasonic XPEDION r5515 PCB substrates

Microfluidic-based sub-THz RIS

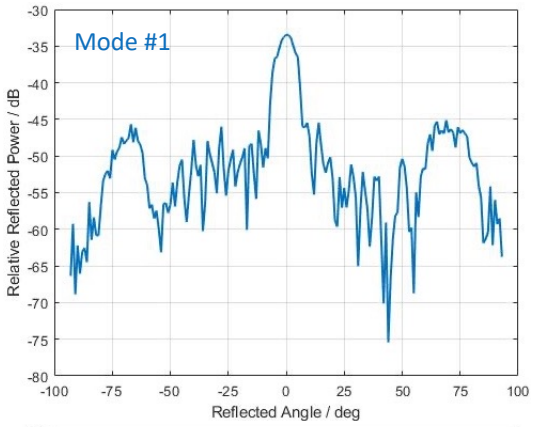
Simulation Results:

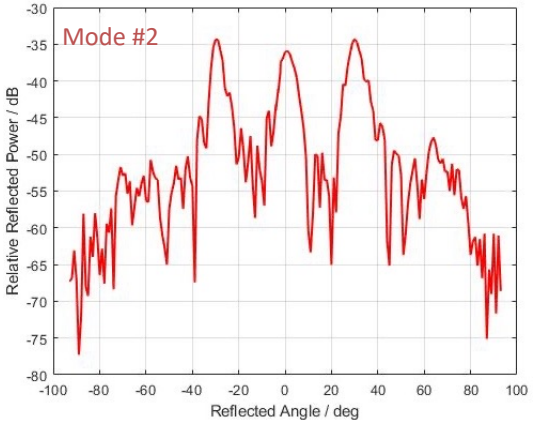
Full-wave simulated scattering patterns from RIS at 150 GHz. The RIS is illuminated by a plane-wave under normal incidence. The scattered pattern can be controlled by modulating the LM pattern on the RIS.

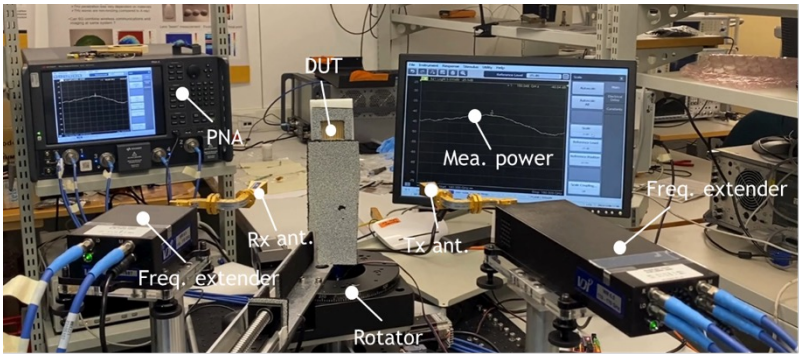


Measurement Results:

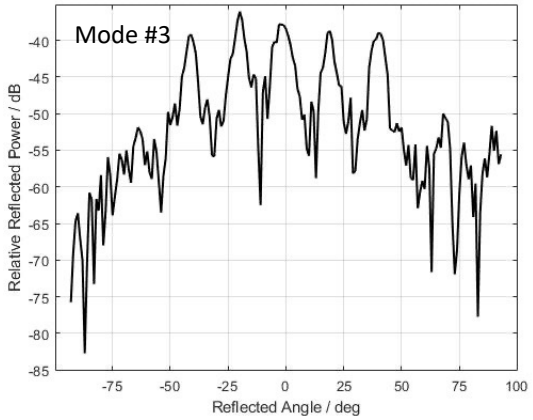
Scattering patterns from RIS under normal incidence can be effectively controlled by reconfiguring the liquid metal pattern on the RIS. This allows for modulation between different modes of scattering.





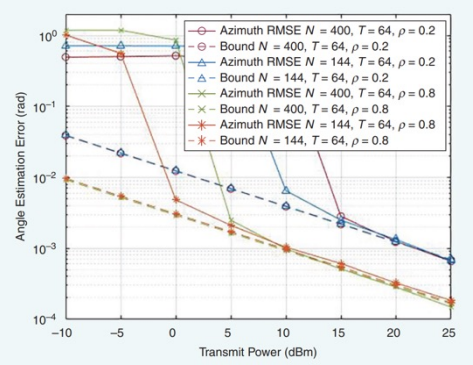


Measurement setup



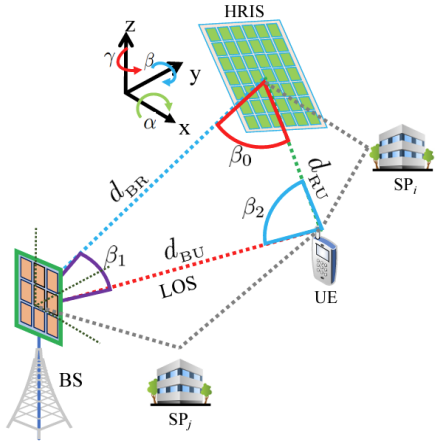
Simultaneous reflecting and sensing RIS

- Typical RIS implementations include metasurfaces with almost passive unit elements.
- This solely reflective operation induces significant challenges for RIS optimization.
- Hybrid reflecting and sensing RISs (H-RISs) metasurfaces are capable to reflect the impinging signal in a controllable manner while simultaneously sensing a portion of it.

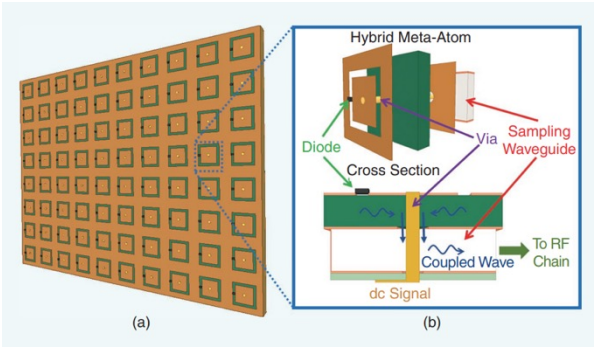


Angle-of-arrival estimation at the HRIS side; ρ is the coupling coefficient and N the number of metamaterials.

- Localization, sensing, as well as simultaneous localization and mapping schemes for HRISs have been investigated within TERRAMETA.
- H-RISs were also considered for joint user 3D and HRIS 6D localization, considering the surface's orientation.

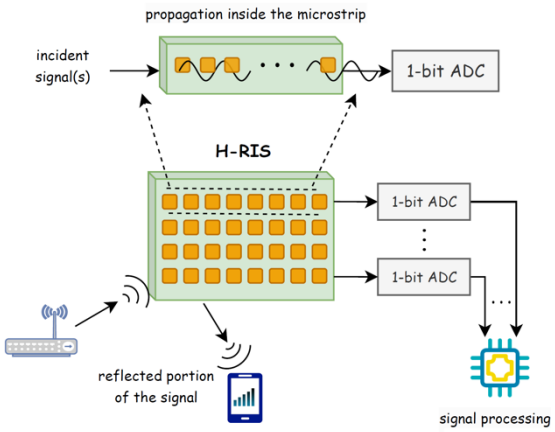


Communication system comprising a multi-antenna BS, a single-antenna UE, and an H-RIS integrating a single reception RF chain.



(a) Designed HRIS and (b) hybrid meta-atom design.

- H-RISs pack large numbers of controllable radiative meta-atoms that are coupled to one or several waveguides.
- Opposed to active relays, H-RISs preserve the power-efficient reflective operation of RISs.
- A very small number of reception RF chains is employed to enable sensing.
- Direction/position estimation can be implemented at the H-RIS, paving the way for self-reconfigurable RISs.

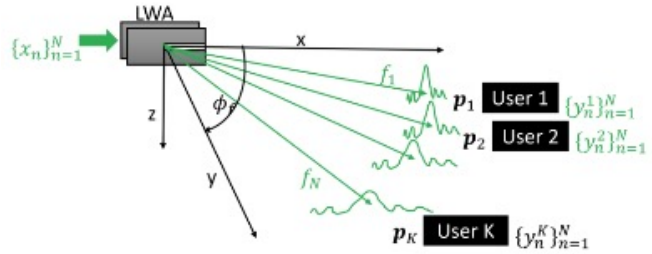


An H-RIS with reception RF chains each include a 1-bit ADC.

- Studied an HRIS architecture with 1-bit ADCs to reduce power consumption.
- Designed an optimization algorithm for multi-user uplink communications, tailored to the proposed hardware architecture.

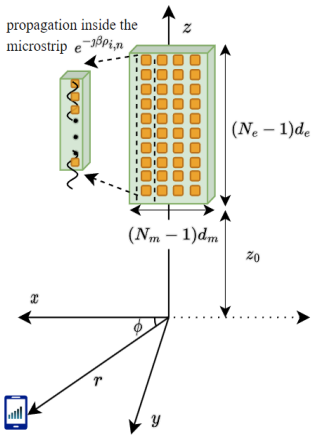
Signal processing for THz multi-functional RISs

- Beamforming algorithms tailored to the particularities of THz frequencies, i.e., wideband beamforming and near-field beam focusing, have been developed.
- An algorithm for serving multiple users with a single leaky-wave antenna via wideband beamforming has been proposed.



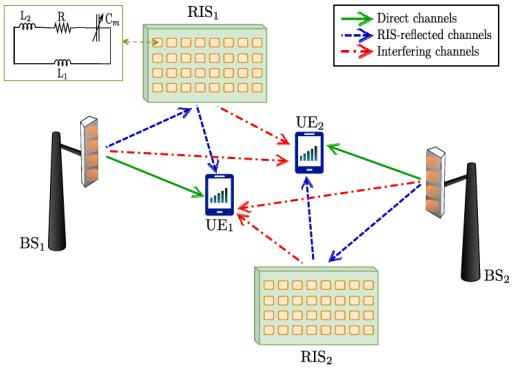
Wideband beamforming for multiple users with a leaky-wave antenna.

- Derived novel analytical expressions relating the beamforming gain to user coordinate mismatch for transmitters equipped with dynamic metasurface antennas.
- Designed a non-uniform coordinate grid for effectively sampling the user's area of interest at each position estimation and proposed a novel near-field beam tracking framework with reduced complexity.



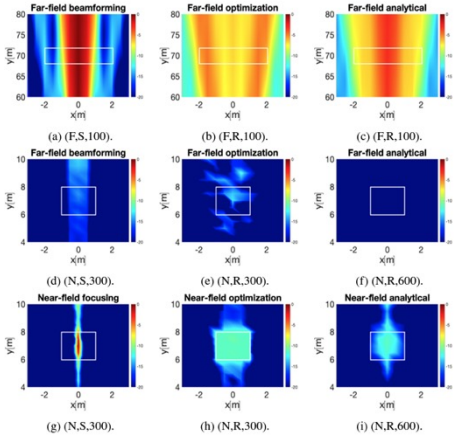
A static metasurface-based base station communicating in the downlink with a user lying in a plane vertical to the transmitter plane.

- Studied a scenario with multiple distributed frequency-selective beyond diagonal RISs in a cell-free architecture.
- Devised an algorithm based on a distributed optimization approach decomposing the overall optimization problem into local sub-problems which were solved in parallel.
- Minimal cooperation strategy required among the base stations.



Distributed optimization of a multi-RIS-empowered multi-access wireless cell-free system.

- Derived analytical and optimization-based beam shaping algorithms for RISs operating in either the far- or near-field.
- Leveraging these methodologies, hierarchical beam codebooks were designed for achieving low-overhead beam training and localization.



RIS codebooks for both near- and far-field operations.

Announcements

SNS ISAC Workshop:

An SNS online workshop on ISAC organized by Hexa-II will take place on October 8, 2024, with the participation of TERRAMETA and other 9 ongoing SNS project working on the topic. TERRAMETA's technical coordinator Prof. Alexandropoulos will present the project's advances on **hardware designs for THz multi-functional RISs along with RIS-enabled schemes for sensing-aided communications and simultaneous sensing and communications**. Apart from a dedicated presentation per project on the topic, the workshop will include keynotes from industrials experts in Asia and USA, as well as a mixed academic/industrial panel moderated by Prof. Alexandropoulos.

B-MRS memristor symposium:

We organize the **"Symposium EP02: Memristor devices from theory to system level integration for next generation of computation and communication**", at Santos – São Paulo, Brazil (September 29th to October 3rd, 2024).

For more information about the event: https://lnkd.in/dSMhTYXY

Our esteemed list of confirmed invited researchers and scientists:

Stephan Menzel (Peter Grünberg Institute, Jülich, Germany)
Valeria Bragaglia (IBM Research Europe, Zürich, Switzerland)
Hannes Raebiger (Yokohama National University, Japan)
Victor Lopez Richard (Universidade Federal de São Carlos, Brazil)
Vitor Tavares (Universidade do Porto, INESC TEC, Portugal)

SANTOS
XXII B-MRS Meeting 2024
September 29th to October 3rd

NOVA
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IEEE ICC 2024 Workshops:

- **2nd workshop on near-field communications, localization, and sensing:** https://sites.google.com/view/near-field-workshop-icc2024
- **3rd workshop on synergies of communication, localization, and sensing towards 6G:** https://sites.google.com/view/icc-workshop-cls-6g

Up-to-date scientific contributions:
- 50 journal/conference publications and dissemination activities available on our website

https://terrameta-project.eu