Terahertz-based ultra-high bandwidth wireless access networks

terapod

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TERAPOD project newsletter #5

September 2020

Welcome to the fifth TERAPOD project newsletter!

It has been a peculiar time since the last TERAPOD newsletter! The travel and working restrictions due to COVID-19 have severely delayed some of the planned activities and a project extension has been required (new end date: 31-May-2021). However, the team has been busy and can report on the following items:

More info is available on the project website www.terapod-project.eu

- World first THz link testing in a data centre at Dell EMC
- 275-320 GHz low barrier SBD mixer at ACST
- Backhaul/fronthaul demo using THz UTC PDs at UCL
- TERAPOD compact RTD transceiver from University of Glasgow
- Beam profile characterisation of emitters for THz wireless links at NPL
- New date announced for 3rd Towards THz Comms Workshop

World first THz link testing in a data centre

DELL EMC UCL

Dell, in collaboration with University College London, has successfully created the first THz wireless link in a data centre to transmit real-world data. The technology which enabled this feat is known as a uni-travelling carrier photodiode (UTC-PD), which converts an optical signal typically used in a data centre to a THz wireless signal. This testing was performed with a fully packaged UTC-PD, bringing the technology one step closer to commercialisation. The results showed that the THz link was capable of performing at the same speed and reliability as a 1 Gbps optical link. The

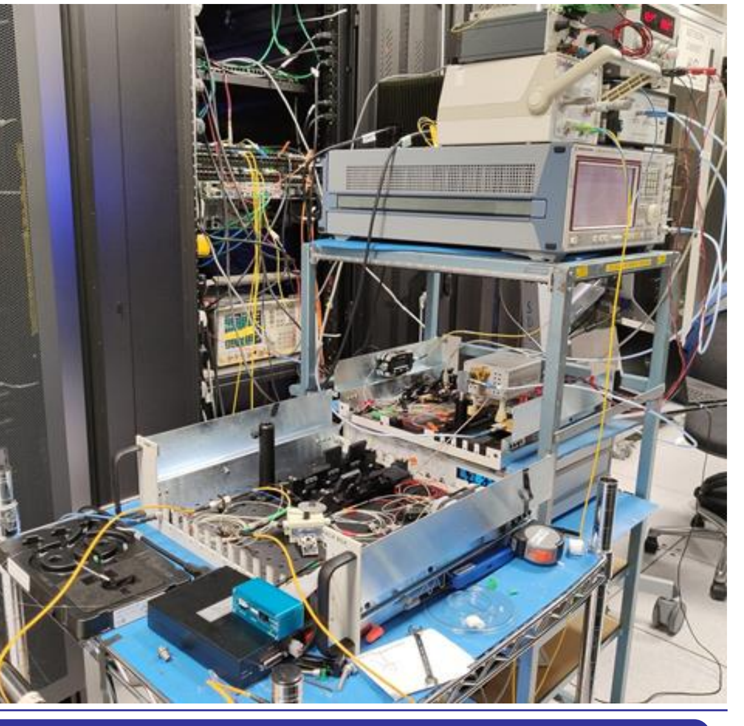

Figure 1: THz link testing using UCL UTC-PDs at DELL EMC's data centre in Cork.

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Waterford Institute of Technology · Technische Universität Braunschweig · VIVID Components · VLC Photonics · ACST Technology Solutions for Terahertz Electronics · NPL National Physical Laboratory · DELL EMC · UCL · INESCTEC · University of Glasgow · bay photonics

high reliability (meaning low data packet loss) is of particular note as it performed much more consistently than traditional wireless technologies such as Wi-Fi or LTE, making it a much more attractive option for data centres. A number of other characteristics which negatively affected the UTC-PD performance were also discovered thanks to this real-world testing. It is planned to resolve these limitations in the next generation of devices, which should enable speeds in the data centre of at least 10 Gbps in 2021.

Definition of network protocols for THz links in a data centre

For the TERAPOD project, Dell has also been working on integrating the control of future THz wireless links as part of a traditional data centre network. Modern data centre networks are created using software-defined networking (SDN) principles, and a key Dell target is to create and define a network architecture and protocols which allow THz wireless links to operate in an SDN environment. Over the course of the TERAPOD project this architecture has been created, and initial testing to show how THz links can operate in an SDN data centre with optical links was published in D5.5 (2019). This was followed by a publication and presentation at the IEEE 5G World Forum in Dresden, Germany. The creation of a network architecture and protocols which fully integrate and utilise THz links in an SDN environment was then created for TERAPOD deliverable D5.6, published in Jun-2020 (see https://terapod-project.eu/results/deliverables).

The IEEE 5G World Forum paper (30-Sep to 02-Oct-2019; Dresden, Germany) was:

Integrating THz Wireless Communication Links in a Data Centre Network

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https://repository.wit.ie/3415 Green link to WIT repository version

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275-320 GHz Low Barrier SBD Mixer

The development of a low barrier Schottky barrier diode (SBD) mixer has been carried out at ACST. A preliminary design using standard GaAs SBDs was developed and tested. The mixer is designed to work in the 270-320 GHz RF frequency range, using a 135-160 GHz local oscillator (LO) frequency signal and a 0-18 GHz IF frequency signal. The implementation of low barrier SBDs (LB-SBDs) allows a significant reduction of the LO power requirements compared with GaAs-SBD based mixers. The first experimental results of LO power requirements obtained from an experimental LB-SBD mixer and comparison with a GaAs based mixer are shown in Fig. 2.

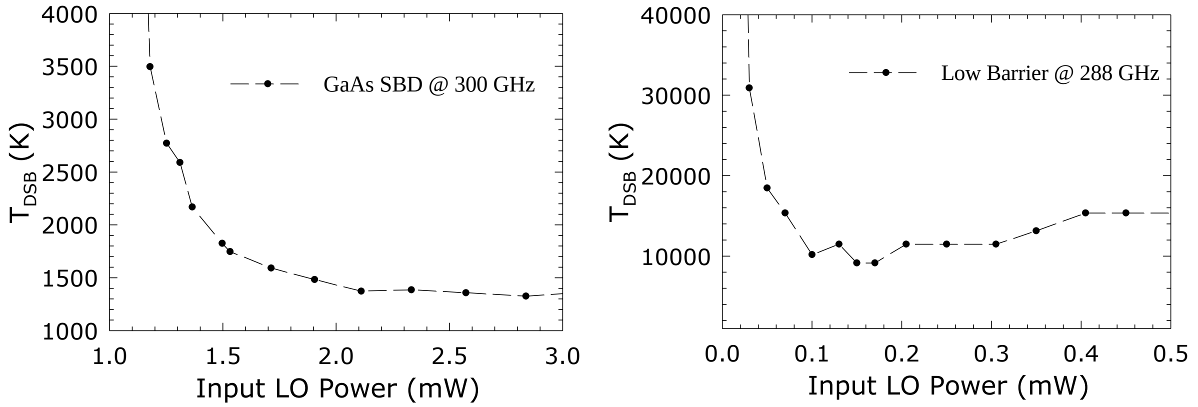

Fig. 2: Noise temperature vs input LO power for a GaAs (left) and a LB-SBD (right) based mixer.

The double side band (DSB) noise temperature of the receiver including a 1.9 dB noise figure in the IF amplifier are plotted in Fig. 2. It may be seen that the input LO power requirements for the LB-SBD based mixer are more than 10× smaller than for the GaAs SBD mixer. However, higher noise temperature is obtained with the first prototype. The reason is not associated with the new technology itself, but to an unfortunate deviation in the electrical properties of the LB-SBDs during the manufacturing process.

The impact of this phenomena is illustrated in Fig. 3, where the experimental noise temperature (black dots) in the 270-320 GHz frequency range has been compared with retro-simulations, accounting for the electrical properties of the experimental manufactured diodes (red line) and the expected diode performance (blue), which shows a better flatness in accordance with the optimised bandwidth for the mixer. The experimental receiver shows a much higher noise temperature (~10000 K) and a significant variation of performance across the band. This can be explained in Fig. 3 (red line) by an unwanted deviation in the capacitance, and hence impedance, of the manufactured diodes and hence a mismatch with the RF chip. The value of the junction capacitance in LB-SBDs is difficult to predict and to measure due to the extremely low threshold voltage of the Schottky contact. A proper definition of the capacitance of the SBDs would allow a reduction in the noise temperature of the receiver to under 4000 K as illustrated by the blue line in Fig. 3. Less than 4000 K is the expected nominal performance of this LB-SBD based receiver.

This 4000 K in the LB-SBD based receiver would be still larger than the 1500 K obtained with the GaAs based receiver. However, the LO power requirement is lower by a factor of 20, allowing a much simpler LO source.

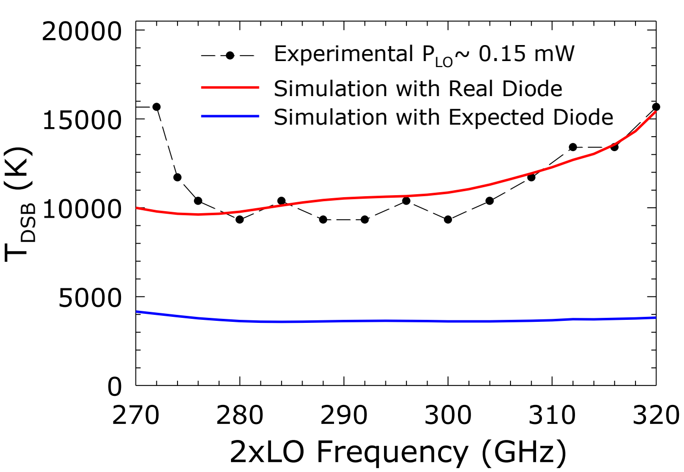

Fig. 3: Noise temperature vs input LO frequency for the LB-SBD based receiver. The experimental results (black dots) are compared with retro-simulations accounting for the experimental properties of the LB-SBDs (red line) and the expected properties (blue). A 1.9 dB noise figure for the IF amplifier is considered.

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Backhaul/fronthaul demo using THz UTC PDs

Researchers at University College London (UCL), in collaboration with Universitat Politècnica de València (UPV) and University of Cambridge, have demonstrated a dual-service antenna unit using a photonic THz emitter developed within TERAPOD. As shown in Fig. 4, the two services feeding the antenna unit were sent from the central office through a multi-core fibre (MCF) provided by UPV. The two signals transmitted in this demonstration were intended for backhauling and fronthauling services, but access services could also be supported by the proposed system. For the backhaul service a 50 Gbps quadrature amplitude modulation (QAM) signal was transmitted at a carrier frequency of 175 GHz using a TERAPOD uni-travelling carrier photodiode (UTC PD) from UCL.

The fronthaul service used a 10 Gbps digital radio-over-fiber signal generated with a novel digital signal processing algorithm developed by University of Cambridge. This signal was transmitted (in a back-to-back fashion due to the lack of suitable antennas) at a carrier frequency of 30 GHz. This demonstration, which is in the process of being submitted to a scientific journal, is one of the first experimental demonstrations of a multi-antenna unit where a range of services are transmitted at different mm-wave and sub-THz frequencies depending on available bandwidth and link characteristics. The results were presented at OFC 2020 in the following paper:

T. Li, L. Gonzalez-Guerrero, H. Shams, C. Renaud *et al.*, "*Novel Compressed Digital Radio Fronthaul over Photonically-generated THz Wireless Bridge*"

In Optical Fiber Communication Conference (OFC) 2020

https://doi.org/10.1364/OFC.2020.Th2A.42 DOI permalink
https://discovery.ucl.ac.uk/id/eprint/10100737/1/OFC2020_final_II.pdf
Green link on UCL repository

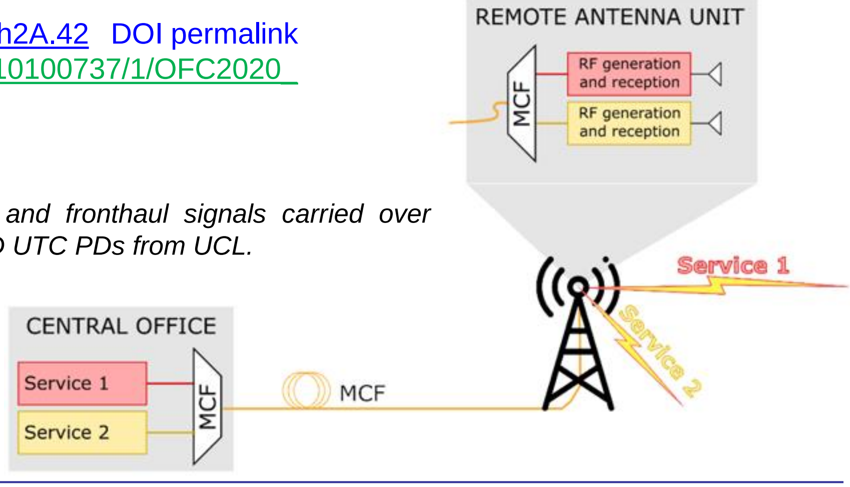

Fig. 4: Schematic showing backhaul and fronthaul signals carried over multicore fibre and based on TERAPOD UTC PDs from UCL.

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TERAPOD compact RTD transceiver

To develop robust low cost Gbps wireless technologies for data centre applications, resonant tunnelling diode (RTD) based transceivers are being developed by one of the TERAPOD partners (UGLA). RTDs are the fastest room temperature operating solid state electronic devices, with fundamental frequencies approaching 2 THz. The technique provides potentially low cost solutions for ultra-high speed wireless links due to possibility of simple transmission schemes such as that shown in Fig. 5.

Researchers at UGLA have demonstrated the first bench-top wireless link (90 GHz) using RTD transceivers. It shows a 1 Gbps data rate with ultra-low packet loss (<0.18 %).

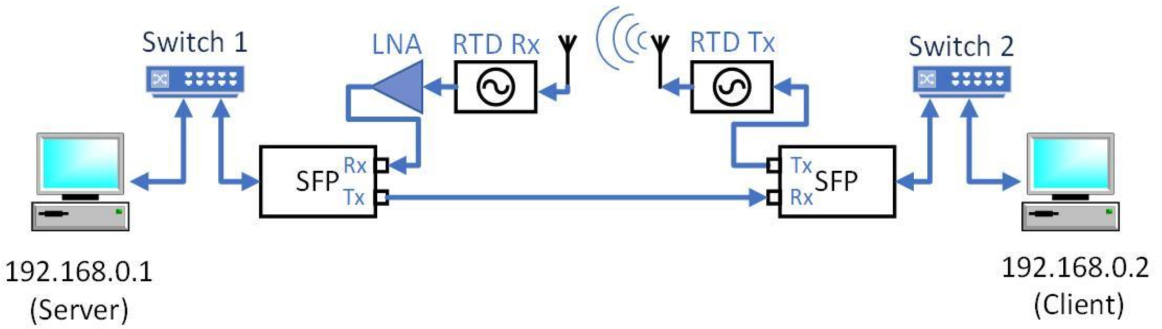


Fig. 5: Schematic showing simple RTD-based wireless link.

This early measurement demonstrates the feasibility of utilising RTD THz transceivers for data centre networks. The TERAPOD work continues to develop long range (tens of metres) robust 300 GHz packaged RTD transceivers using UGLA pioneering high power THz transmitters.

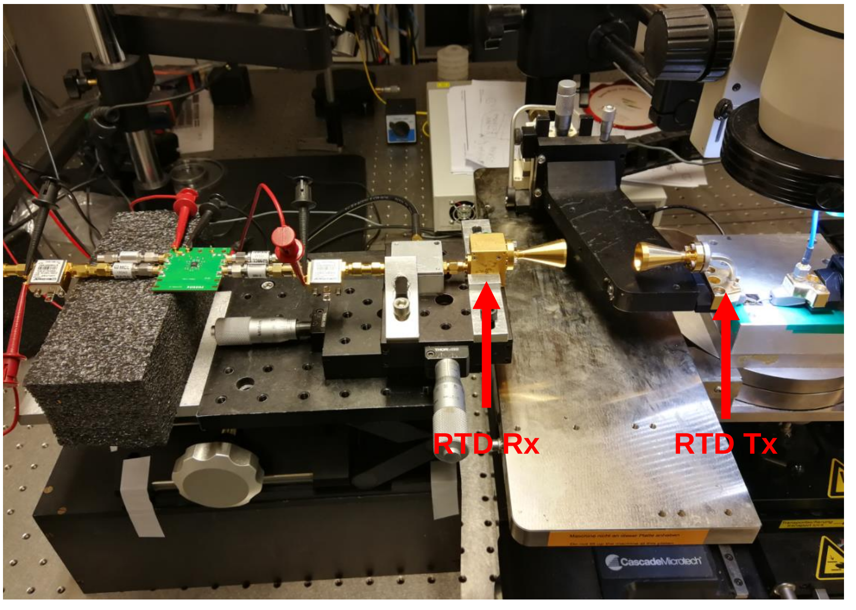


Fig. 6: Laboratory implementation of the link at UGLA.

RTD device technology

Fig. 7 shows the measured oscillator spectrum of a 4×4 μm^2 double RTD oscillator with an 88 μm long 10 Ω microstrip shorted stub (Fig. 8). The fundamental oscillation was at 260 GHz with 1 mW output power. The line width was 2 MHz at -10 dB below the peak power, indicating that the oscillators have relatively low phase noise.

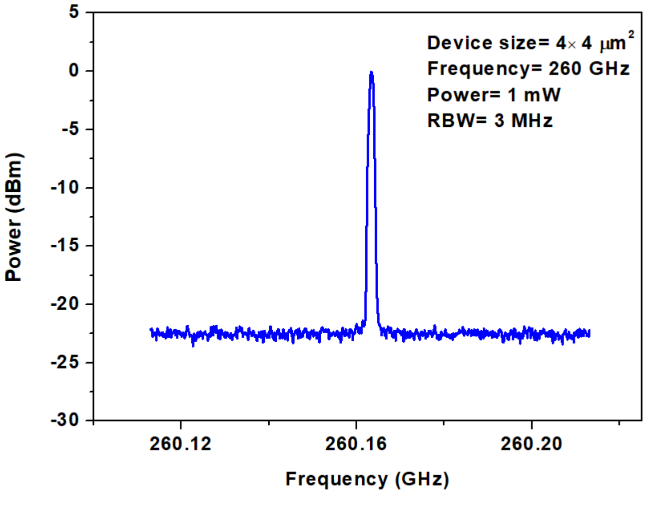


Fig. 7: Measured spectrum of the RTD oscillator circuit.

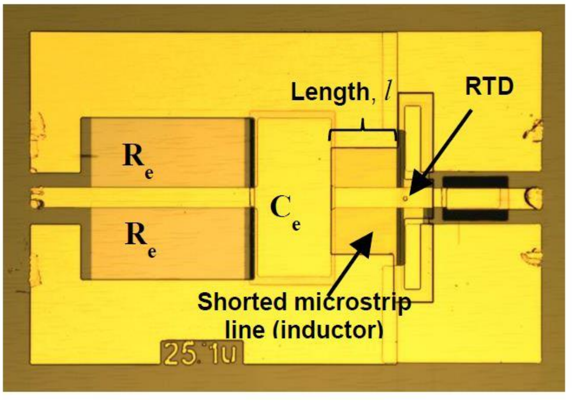
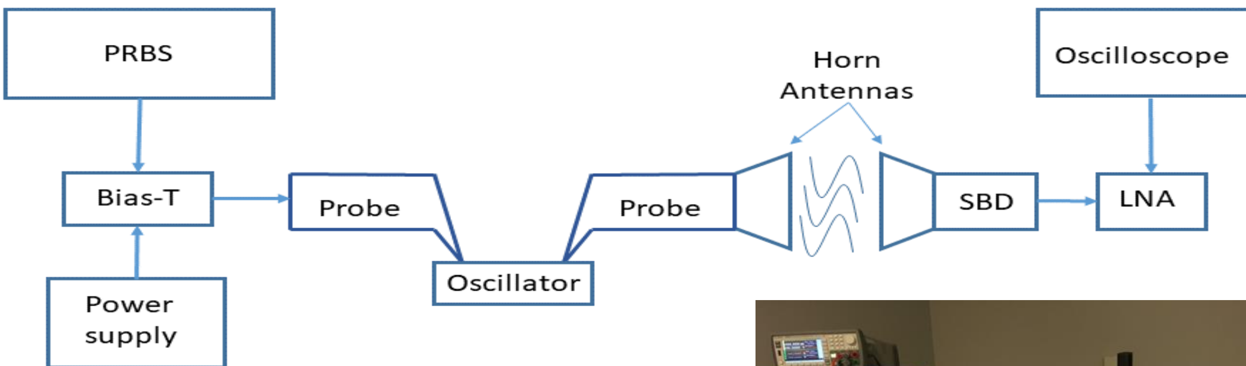


Fig. 8: The fabricated RTD oscillator circuit.

RTD wireless link

A schematic of the wireless experimental set-up is shown in Figure 9. A pseudorandom binary sequence (PRBS) data generator (Anritsu MP1763C) is clocked using an internal signal generator. A bias-T connected to a 67 GHz probe is used to relay both the DC bias and the data from the PRBS to the DC port of the oscillator. The oscillator output (RF port) is connected via a GSG probe (including waveguide transition) to a 300 GHz horn antenna to transmit the output signal (carrier + data) which is received by second 300 GHz horn antenna that is connected to a SBD detector (WR3.4ZBD from VDI). The SBD is connected to a low noise amplifier from VDI which feeds the data into a sampling oscilloscope. The oscilloscope uses the same clock that is used to clock the PRBS and data from the SBD to generate the eye diagrams. The measurement set-up is illustrated clearly showing the 10 Gbps eye diagrams at a range of 30 cm.



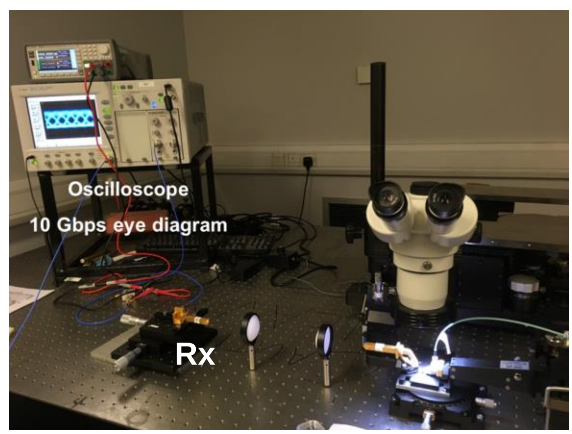


Fig. 9: Schematic of the wireless experimental set-up and photo of lab implementation showing 10 Gbps eye diagram.

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Beam profile characterisation of emitters for THz wireless links

An essential aspect of building THz wireless links and networks will be standardisation of device specifications based on standard procedures for device characterisation. In particular, the radiation patterns of emitters must be determined for the purposes of link design and operation. Although there are extensively developed and well understood techniques for antenna characterisation, and specialised facilities to perform the required measurements, none of these as yet exist for THz devices. THz emitters produce relatively low powers (commonly <100 μW) and there is a lack of compact high sensitivity detectors. On the other hand, the short wavelengths enable far-field measurements on a bench-top.

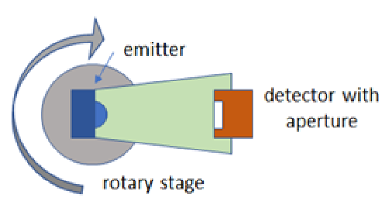

Fig. 10: A schematic depiction of the set-up at NPL for THz emitter beam profile measurements.

Using the set-up in Fig. 10 at NPL, the beam profiles of UTC-PDs from UCL were recorded along both emitter axes: parallel (E-field) and perpendicular (H-field) to the emitter polarisation. The power was measured by a calibrated pyroelectric detector (SLT, calibrated by PTB). The detector aperture was 4 mm, and the distance between emitter and detector was 12 mm, which was calculated to be within the far-field of the emitter.

Figure 11 shows an example of observed beam profiles of a UTC in H- and E-planes. It is seen that in all cases there are significant extraneous features in addition to the central lobe. The beam profiles are both frequency- and orientation- dependent. These results demonstrate the importance of measuring the beam profiles of emitters. Beam profile and beam divergence strongly affect receiver efficiency, and therefore must be taken into account in designing receiver antennas and beam steering optical components.

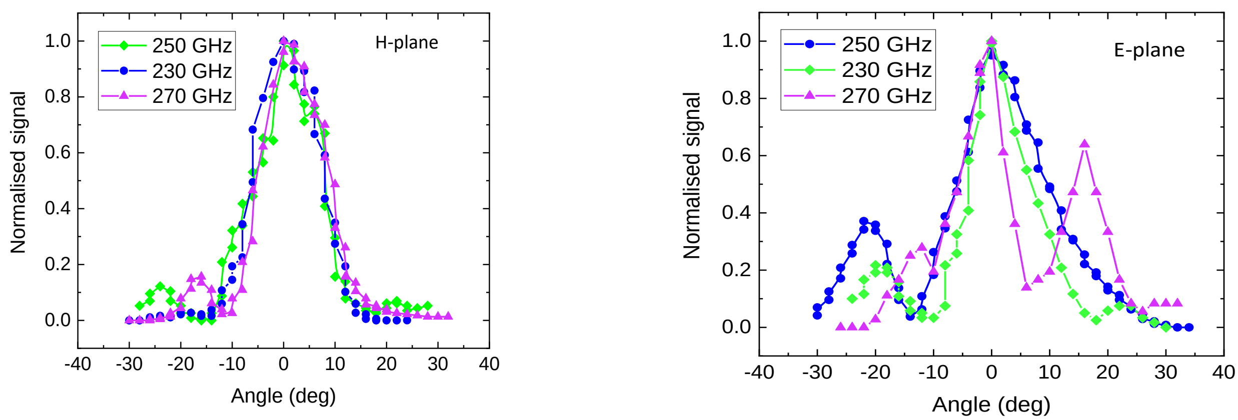

Fig. 11: Normalised beam profiles of a UTC emitter in the H- and E-planes.

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New date announced for 3rd Towards THz Communications Workshop

11-12 Mar-2021; IMEC (Leuven)

SAVE THE DATE

The Beyond 5G Cluster has organised two previous workshops on THz communications. Unfortunately, the 3TTCW scheduled in Mar-2020 had to be postponed due to COVID-19 restrictions. However, we are pleased to announce a new date for the event: it will be held at IMEC (Leuven, Belgium) on THU/FRI 11-12 Mar-2021. There will be an evening reception on THU 11-Mar, and a workshop on FRI 12-Mar-2021 including guest speakers and a panel session. More details will be released on the workshop website soon!

https://terapod-project.eu/terapod_events/3rd-towards-thz-comms-workshop

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