Terahertz-based ultra-high bandwidth wireless access networks

TERAPOD is a research project supported by the European Commission through Horizon 2020 under Grant Agreement 761579.

TERAPOD project newsletter #7

August 2021

(An extra project update newsletter!)

Although TERAPOD concluded on 31-May-2021, the consortium would like to release this extra newsletter to update on progress over summer 2021.

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

In this bonus edition, please find details on the following topics:

- The final online workshop was held in May 2021! See below!!
- Substrate integrated sub-THz antenna array at INESC
- WIT progress in THz link establishment algorithms
- Simulation demonstrator for top-of-rack links by TU Braunschweig
- NPL THz characterisation suite

More information on these and many other topics will be provided in the official public report in Q4 2021. This will be available on CORDIS:

https://cordis.europa.eu/project/id/761579

Please also check the website for links to almost fifty conference presentations and a dozen journal papers on TERAPOD work.

TERAPOD final workshop

TERAPOD held its final workshop and live demonstration on WED 26-May-2021. The event attracted over fifty external attendees and included a wide variety of presentations from the consortium members. The highlight of the event was the set of three live demonstrations held in the afternoon:

Simulation demo: THz links in a data centre
Johannes Eckhardt; TU Braunschweig

Link demo-1: 3 Gbps HDMI using RTD
Jue Wang; University of Glasgow

Link demo-2: 10 Gbps THz link using UTC
Cyril Renaud; University College London

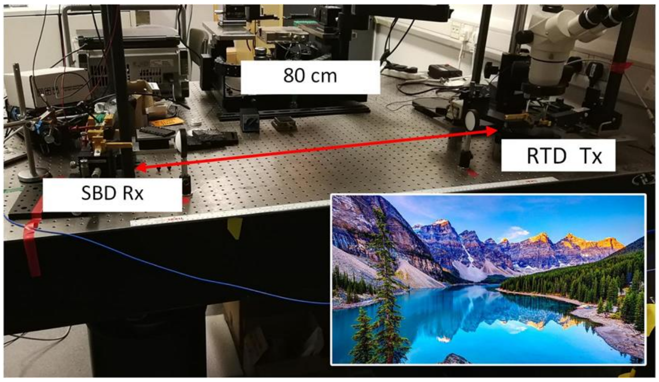

Fig. 1: The University of GlasgowTHz link demo.

Copies of the slides may be found on the website: https://terapod-project.eu/terapod_events/terapod-final-workshop

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Substrate integrated sub-THz antenna array

In the sub-THz domain, the fabrication challenges of indium phosphide (InP), namely the isotropic etching profile and extreme thinning required for the substrate, strongly limits the design of on-chip antennas. As the wavelength inside an InP substrate is approximately 283 µm at 300 GHz, the required substrate thickness is <50 µm for the realization of a microstrip structure. Instead of using InP as substrate, in TERAPOD we proposed the employment of an additional organic dielectric layer of benzocyclobutene (BCB), deposited over the InP substrate, with a metallic ground plane that acts as a shield to avoid the signal from back-radiating through the high dielectric constant InP substrate underneath. We proposed to connect the ground-signal-ground output pads of the UTC-PD to a capacitively coupled patch antenna structure, thereby eliminating the need of substrate thinning or plasma etching for the realization of via-holes. The proposed antenna structure is shown in Fig. 2. The signal pad is connected to the capacitive feed using a via through the BCB layer 1 with a height of 4 µm. The choice of height is dictated by the cavity etching requirements of the BCB material. As the ground planes are not transported to the BCB layers, only a single via-hole is needed.

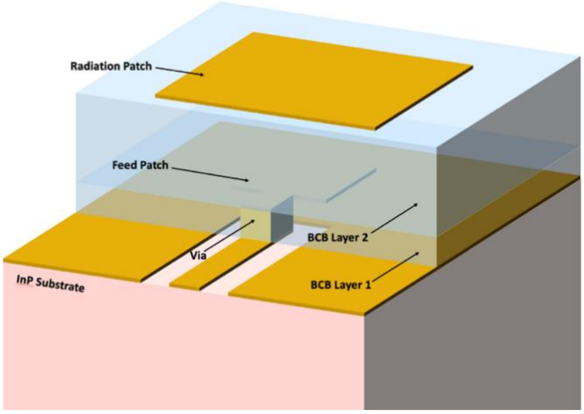

Fig. 2: Proposed antenna structure.

As shown in Fig. 2, a square patch is used as an antenna feed, and a square shaped radiation patch is deposited over the top of the BCB layer 2. We know that the antenna efficiency increases with the vertical distance between the radiation patch and feed patch. On the other hand, BCB layers tend to start forming cracks for thicknesses higher than 15 µm. Therefore, the distance between the patch feed and the radiation patch was kept at 10 µm. The thickness of the two BCB layers is 14 µm in total.

Fig. 3 shows the top view of a fabricated antenna element. In order to provide a DC-bias to the photodiode, a microstrip based bias line was implemented as shown, which includes two radial stubs such that the impedance of the antenna element becomes the complex conjugate of the photodiode's output impedance. The DC-bias line blocks the sub-THz signal at 300 GHz by providing an isolation better than 20 dB. The microstrip structure is implemented by depositing a silicon-oxynitride (SiOxNy) layer (500 nm thickness). The added SiOxNy layer provides strong adhesion between the BCB layer and metallic (gold) ground plane. A similar adhesion layer is deposited between the top BCB layer and the radiation patch.

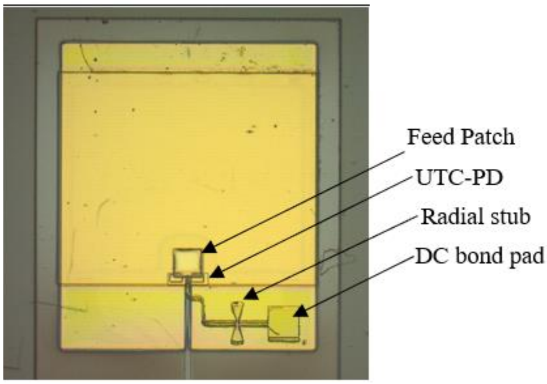

Fig. 3: Top view of fabricated antenna element.

After finalizing the unit-cell (which provides a gain of 2.4 dBi with a radiation efficiency of 46.7 %), a 1×4 planar antenna array was created as shown in Fig. 4. The planar one-dimensional design provides design flexibility for the optical routing. The array structure was simulated, and the results are presented in Fig. 5. It can be observed that the array has the capability of beam steering over an angular range of 60º in the broadside direction. The half power beam width is approximately 26º and the side lobe levels (SLL) are better than 10 dB for the specified steering angles. Note that the limits of beam steering can be increased to +/-90º by compromising the SLL performance.

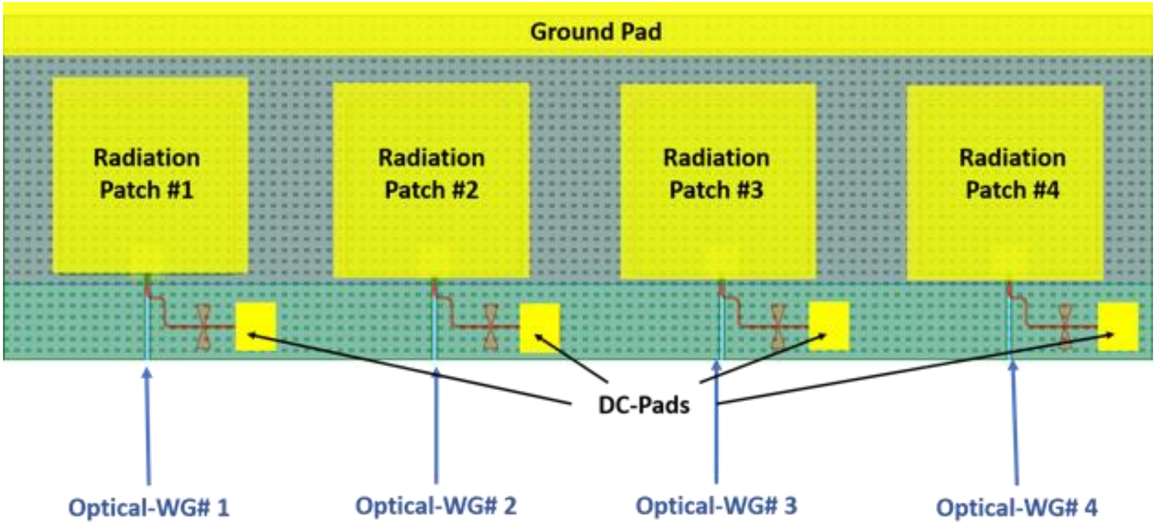

Fig. 4: Finalized mask layout of 1×4 array.

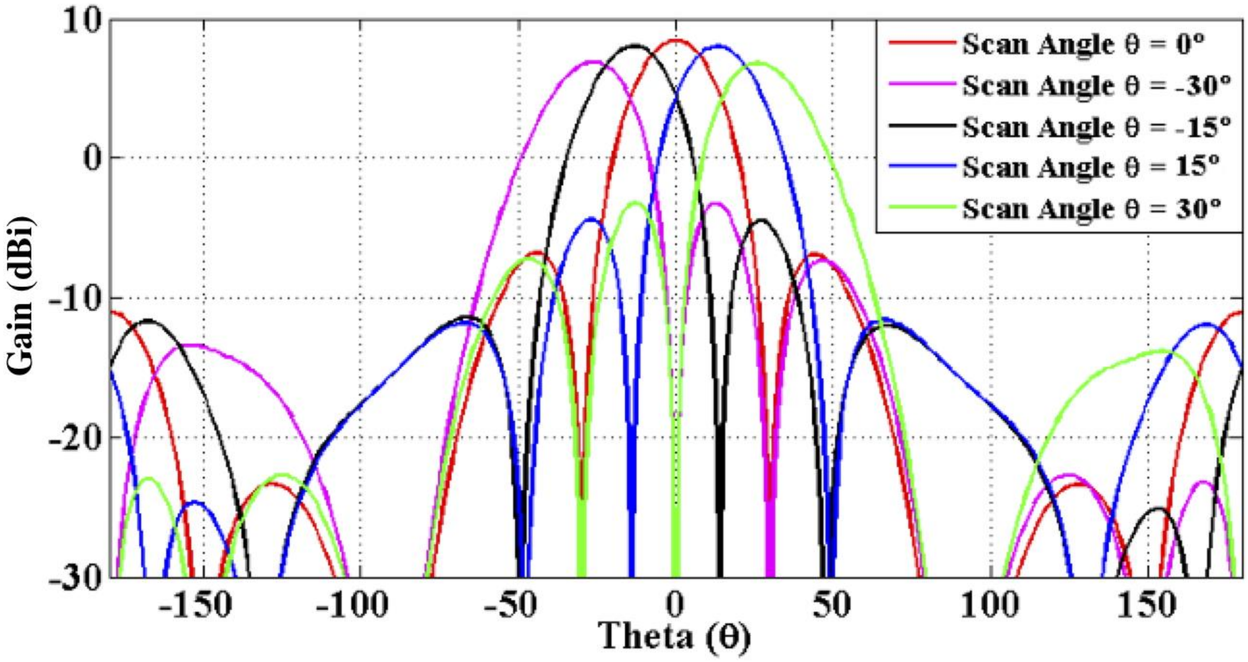

Fig. 5: Simulated gain of antenna array for different scan angles.

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Link establishment algorithms for THz *ad hoc* networks in data centres

Waterford Institute *of* Technology

In previous work, we investigated models and algorithms for centralized networks and proposed medium access techniques suitable for top-of-rack THz architecture and system requirements.

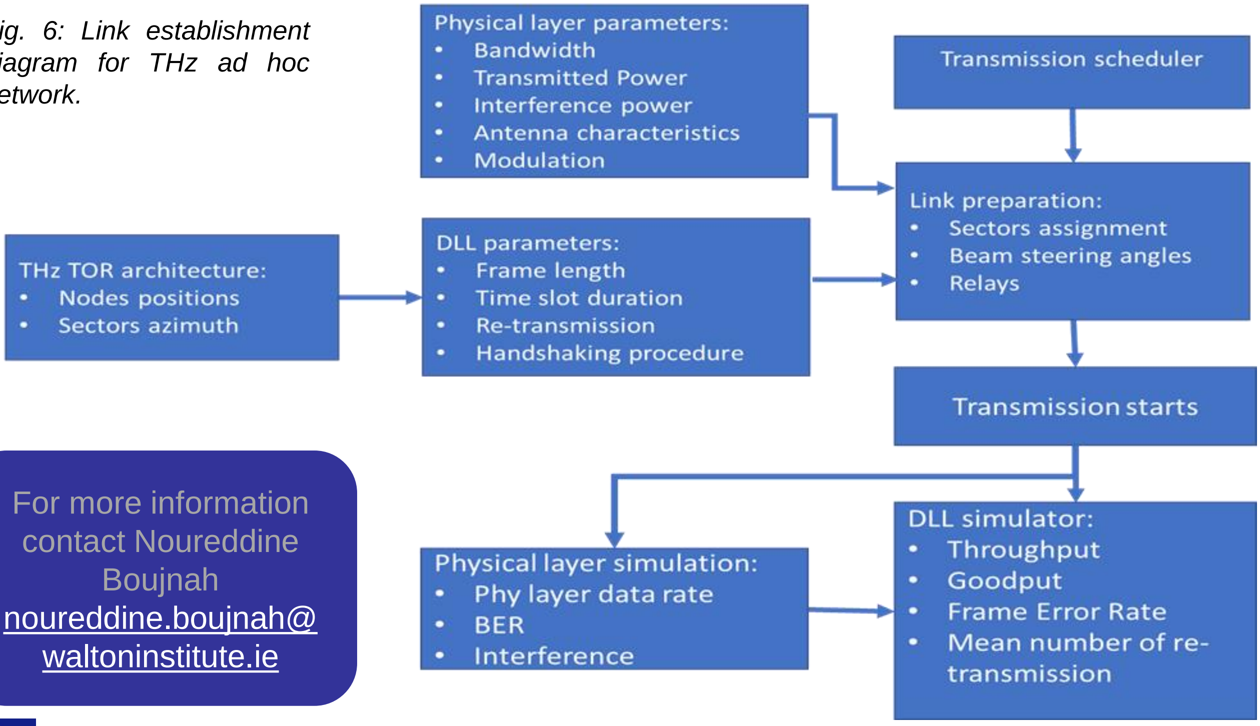
During the last six months of the TERAPOD project, we investigated the feasibility of designing *ad hoc* THz networks within a data centre, using node sectorization and steerable THz beam based on a 16×16 high gain phased array. The link budget was optimized to operate for ranges reaching 10 m. In these *ad hoc* THz networks, each node in the network can communicate with any other node where a line of sight exists.

Models for sector selection, beam steering and relays were proposed for the *ad hoc* network based on DC network geometry and inputs from physical layer studies as well as a physical layer simulator.

The sector angular range is 90°, and the beam is steered within this angle. The sector and beam orientation is selected in order to optimize the link budget between transmitter and receiver. However, a wireless link can be subject to multiple impairments due to distance or interference from other active links. An interface between the physical layer and data link layer (DLL) was created including bit error rate (BER) data and an interference matrix. This interface can help the DLL in the selection of frame size and error control technique to improve the link quality. The link establishment diagram for such an *ad hoc* network is described in Figure 6.

The phased antenna proposed by INESC introduced some excellent reconfigurability to the system, but some modifications and additional optimizations in the DLL were required to keep a good quality link, for instance new path selection, frame size adaption and introducing feedback information on link quality forwarded by the receiver.

Fig. 6: Link establishment diagram for THz ad hoc network.



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Simulation demonstrator for top-of-rack links

The final activity within TERAPOD of the Technische Universität Braunschweig was the development and simulation of a data centre network with 16 racks equipped with top-of-rack antennas. The simulation demonstration scenario uses all simulation techniques that were developed within the project. 16 racks grouped in four rows are placed in the middle of the 3D model of the Dell EMC Research Data Centre (see Fig. 7).

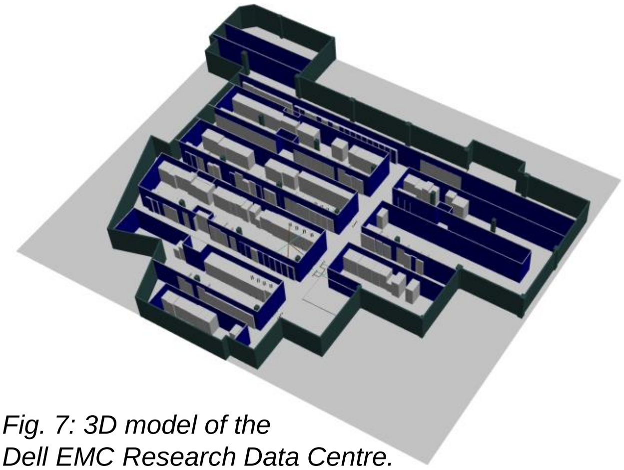

Fig. 7: 3D model of the Dell EMC Research Data Centre.

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Three events such as a link failure detection procedure and an interference detection mechanism are implemented representing a realistic link configuration of a wirelessly augmented data centre network. An exemplary link configuration is shown in Fig. 8.

The propagation in this top-of-rack scenario is simulated using the ray tracing module of the Simulator for Mobile Networks (SiMoNe). Here, beam-steerable antenna arrays of our TERAPOD partner INESC are taken into account. A simulation result of a selected link is visualised in Fig. 9.

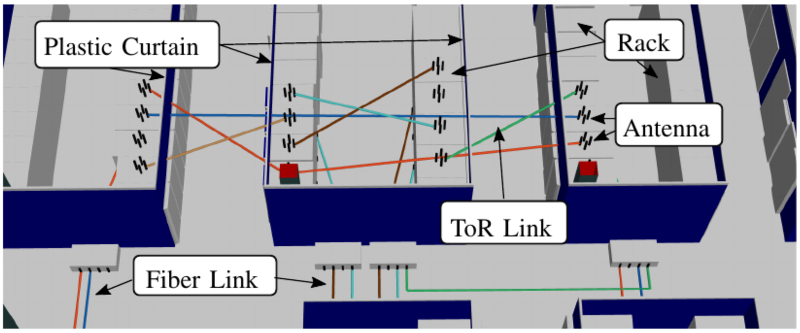

Fig. 8: Top-of-rack visualisation of the 4×4 data centre network.

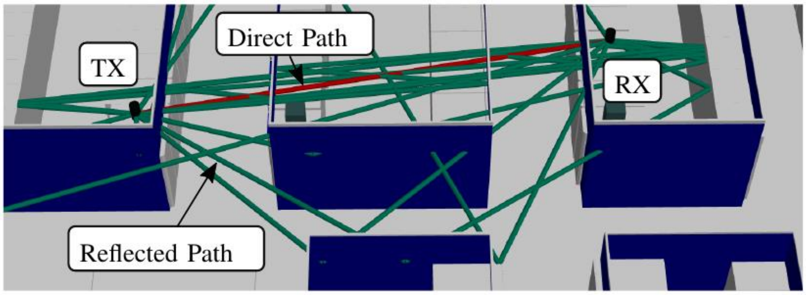

Fig. 9: Visualisation of the ray tracing for a selected top-of-rack link.

The defined links are separated to quasi-static states with an associated interference configuration of the respective links being active in parallel. First, the impulse responses of the interfering links from the ray tracing are fed into the link level simulator developed in TERAPOD and the received signals are superposed at each receiver for each state. Then, the actual top-of-rack links are simulated in the link level simulator that is compliant with the IEEE 802.15.3d THz-SC PHY configuration and considers RF impairments such as phase noise and frequency dependent gains. In this way, the bit error rate and signal-to-interference-plus-noise ratio are evaluated. The scenario demonstrates that interference has to be considered and mitigated despite highly directional communication links.

NPL THz characterisation suite up and running!

In the course of TERAPOD a suite of device characterisation instruments were developed at NPL as part of WP4. Of particular interest and utility are: broadband spectral profile of emitters, spatial profile of emitters, and acceptance cone of detectors. *This equipment is available for assessment and characterisation of THz sources and detectors from third parties and NPL welcomes enquiries for collaboration.*

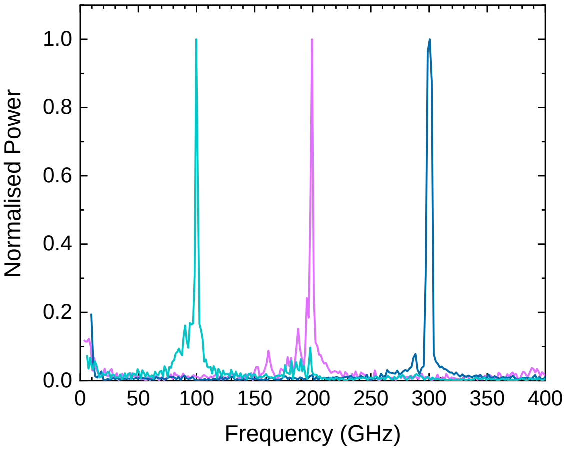

Fig. 10: Spectra of a photoconductive emitter at different frequencies.

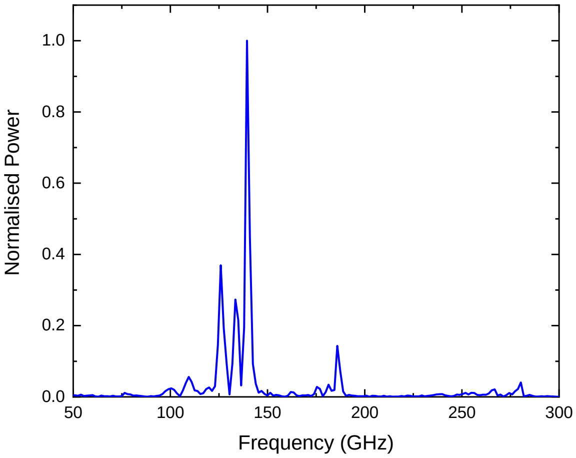

Fig. 11: Spectrum of an electronic source at a nominal 140 GHz.

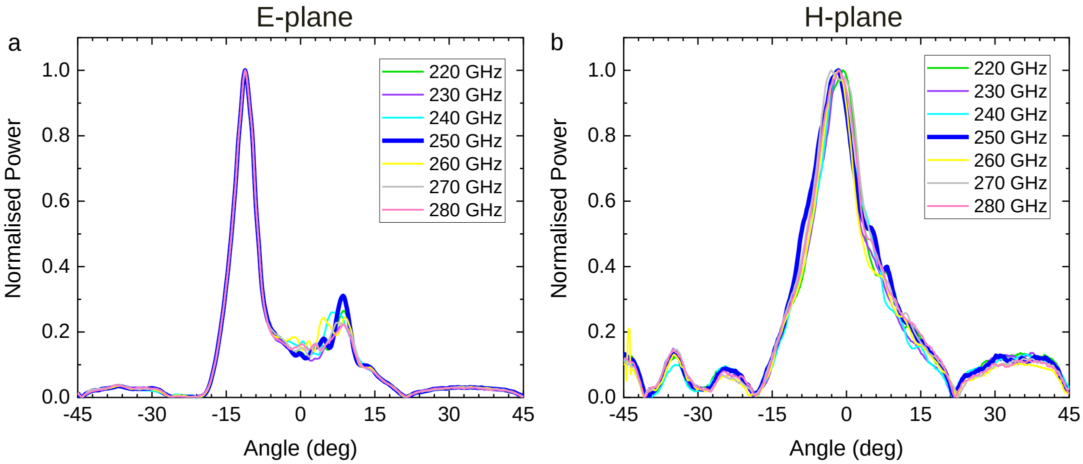

Fig. 12: Spatial beam profile of a TERAPOD UTC emitter.

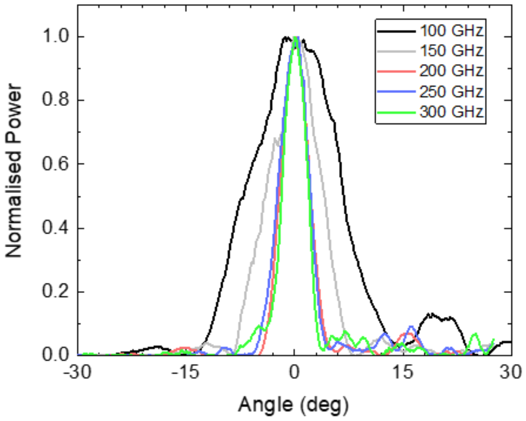

Fig. 13: (Left) Acceptance cone of a TERAPOD detector.

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