Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: 100 Gb/s Real-Time THz Wireless Link Demonstration
Date Submitted: 15 July 2019
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Re: n/a
Abstract: In order to demonstrate the feasibility of THz systems for a future beyond 5G networks, we have constructed a 100 Gb/s real-time spatially-multiplexed THz wireless link, which operates at a carrier frequency of 300 GHz, and investigated its transmission performance using a broadband digital-coherent modem. In addition, we provide an overview of our previous >100Gb/s transmission experiments to highlight the special characteristics and considerations for purely wireless and for hybrid optic-THz links.

Purpose: Information of the Technical Advisory Group THz

100 GB/S REAL-TIME THZ WIRELESS LINK DEMONSTRATION

IEEE 802 Plenary Session,

121st IEEE 802.15 WSN Meeting – Austria Congress Centre

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H2020 EU TERRANOVA: Terabit/s Wireless Connectivity by TeraHertz innovative technologies to deliver Optical Network Quality of Experience in Systems beyond 5G

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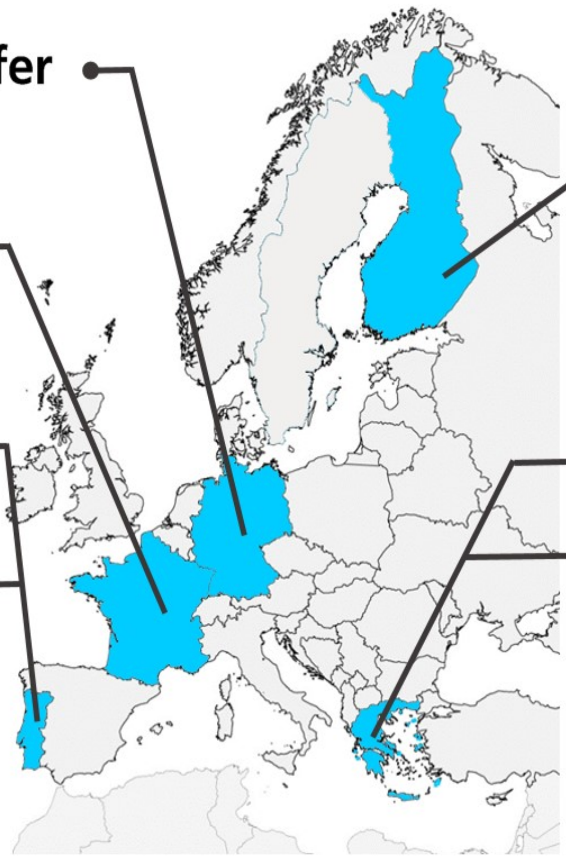

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ICT-09-2017 – Networking research beyond 5G

Duration: 7/2017 – 12/2019

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OUTLINE

- Hybrid optical-THz wireless networks beyond 5G
- 100 Gb/s offline experiments
- 100 Gb/s real-time experiments
- Conclusions

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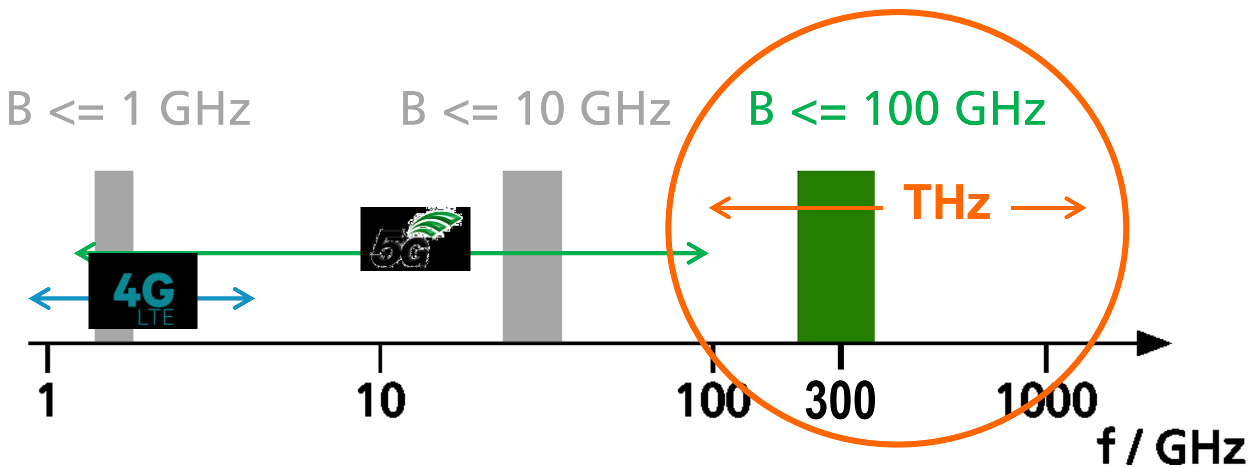
THz communications as enabler for flexible hybrid networks beyond 5G
Motivation

- THz wireless data transmission at carrier frequencies in the 100 GHz – 1000 GHz range
  - Large bandwidth, compatible with state-of-the-art fibre-optical transmission systems
  - This allows to design **flexible hybrid optical-THz wireless networks beyond 5G with seamless interconnections and > 100 Gb/s link capacity**



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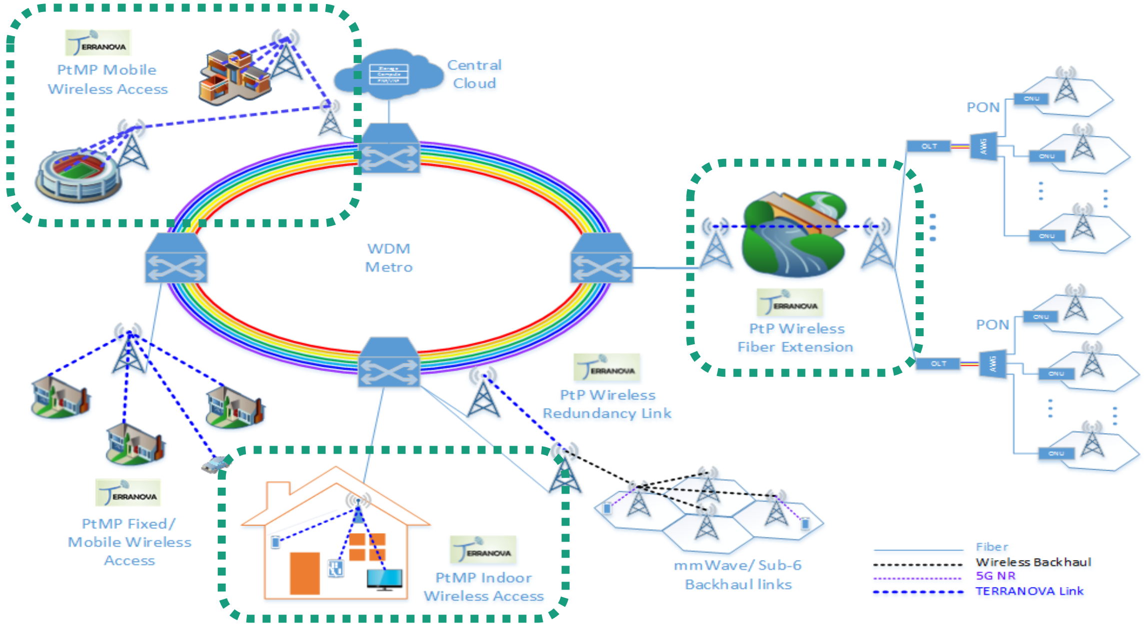
Applications for THz wireless networks



- Applications can be classified in 3 generic technology scenarios:
  - Quasi-Omnidirectional
  - Point-to-Multi-Point (PtMP)
  - **Point-to-Point (PtP)**

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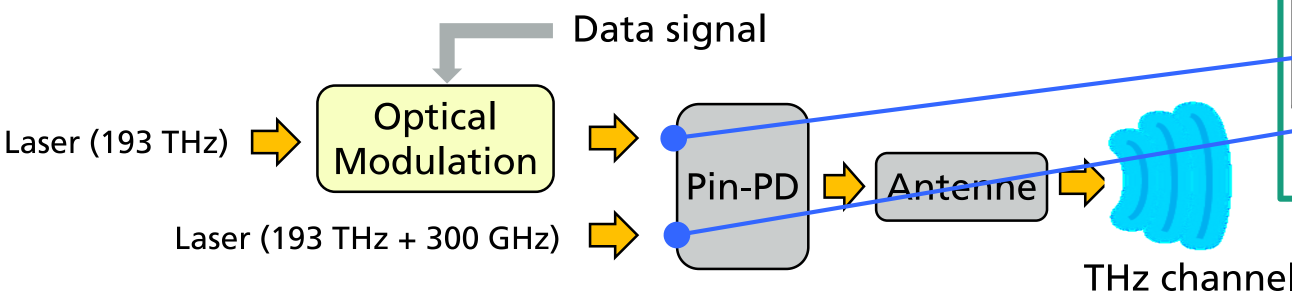
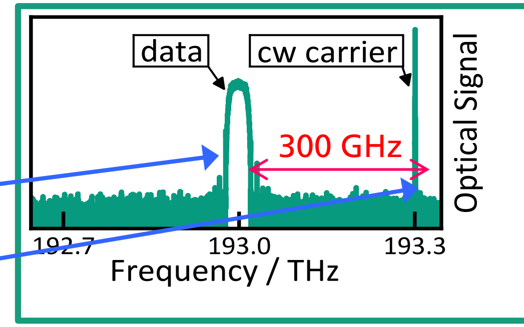
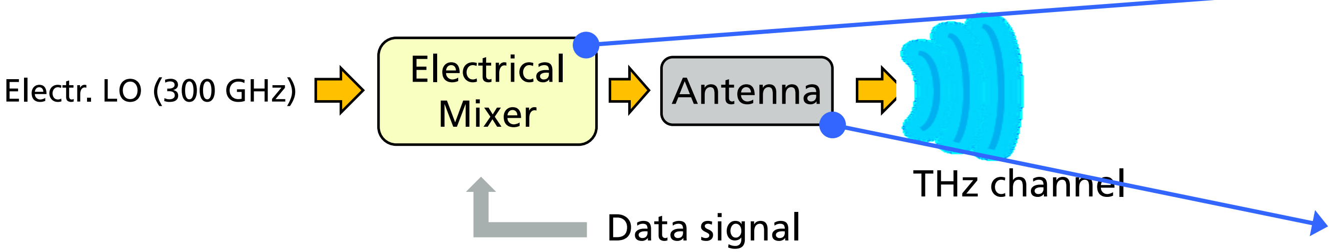
Techniques for THz upconversion

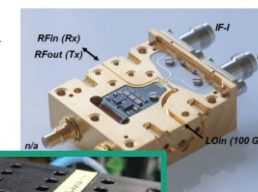
- Optical THz upconversion

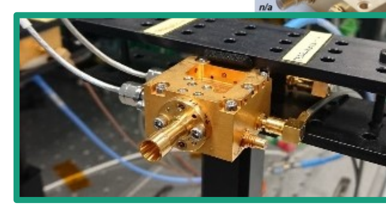




- Electrical THz upconversion







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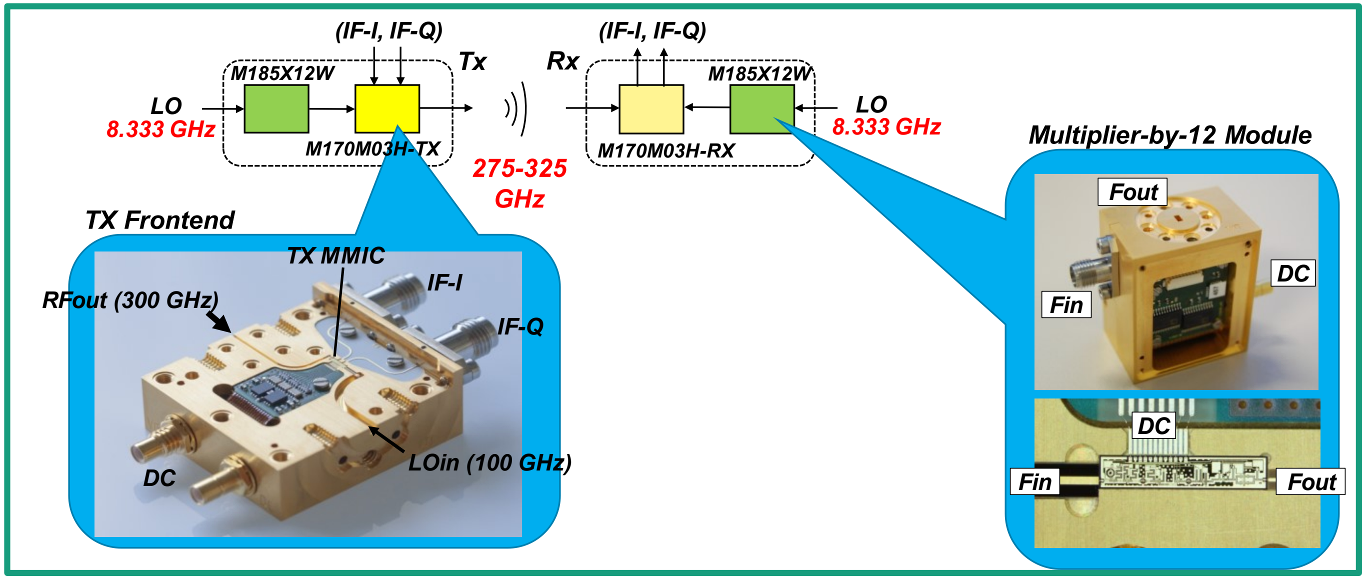
275-325 GHz THz frontend waveguide modules (Tx/Rx)



- **All-electronic up- and down-conversion**
  - LO generation using 2-stage multipliers (x12, x3) and direct-conversion architecture

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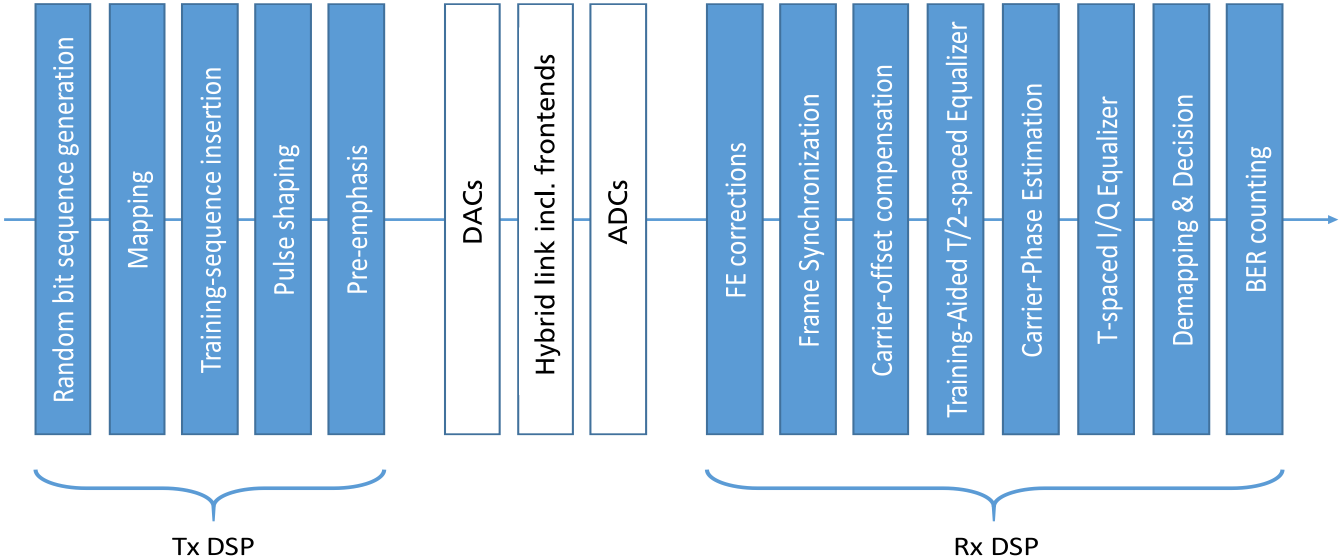
DSP Algorithms and Modem Functions



- THz PtP LoS channel is very similar to fibre-optical channel: relatively flat within the bandwidth of a signal)
- Typical single-carrier PHY DSP for optical channels can also be used for THz PtP LoS channel (but additional adaptivity required)

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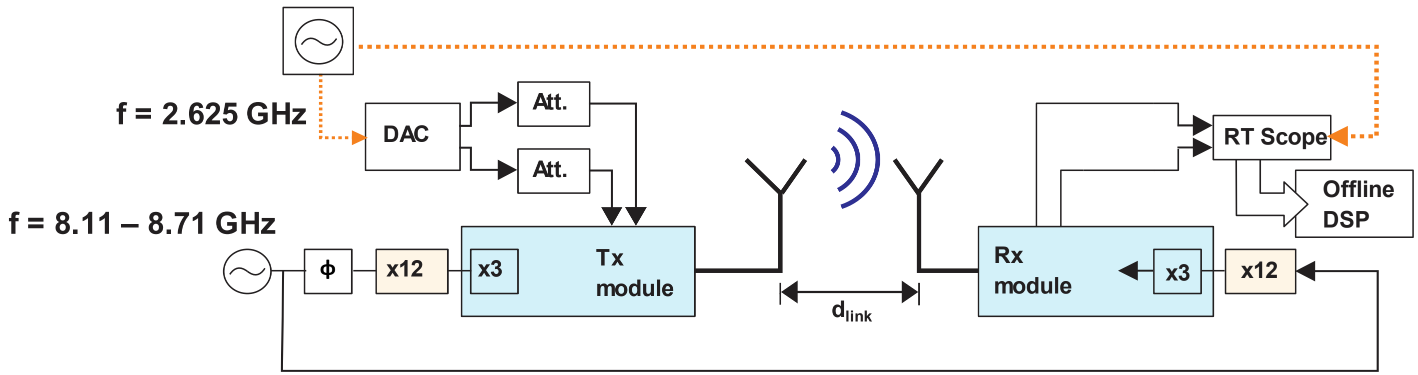
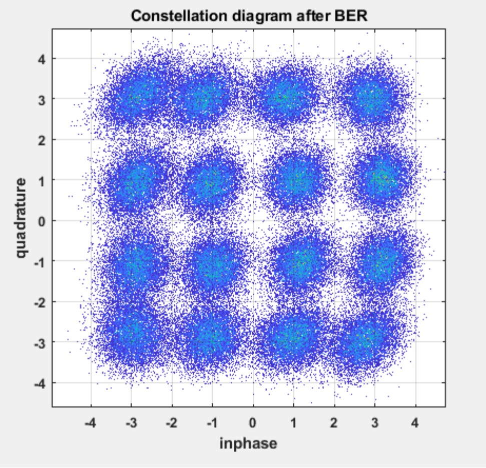
All-electronic 100 Gb/s THz wireless transmission experiment (offline)



300 GHz carrier / 23 dBi antennas

- One spatial channel
- Distance (wireless link): 58 cm
- Radiated THz power at Tx: ~14 dBm
- 32 Gbaud – 16 QAM

- Raw 128 Gb/s @ BER = $1.1 \cdot 10^{-2}$
- Net 100 Gb/s FEC-corrected



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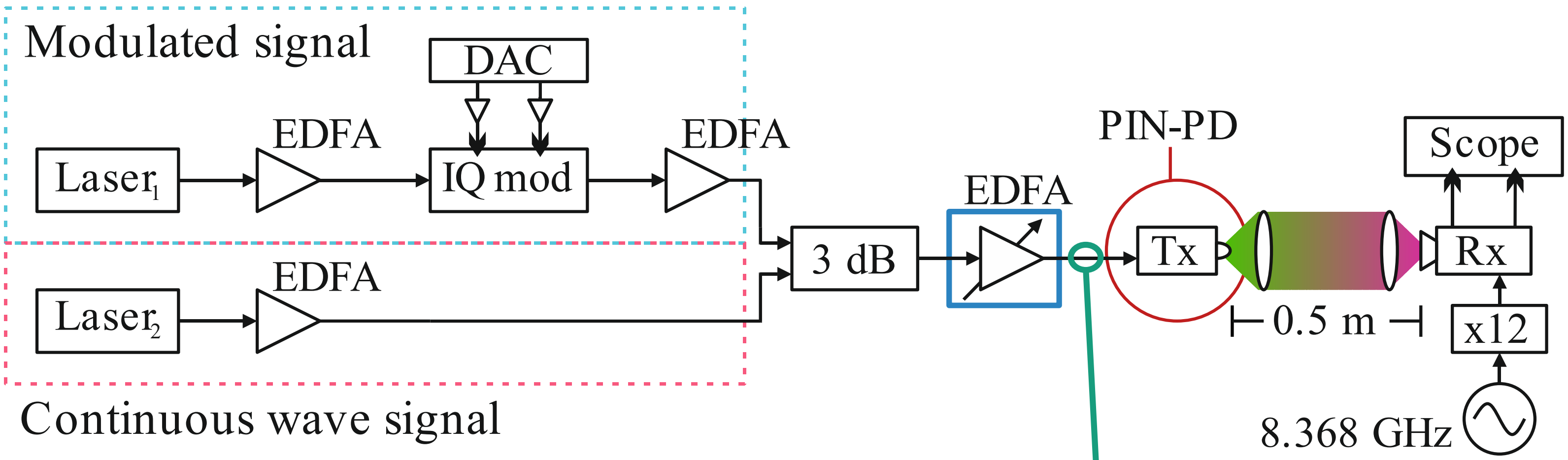
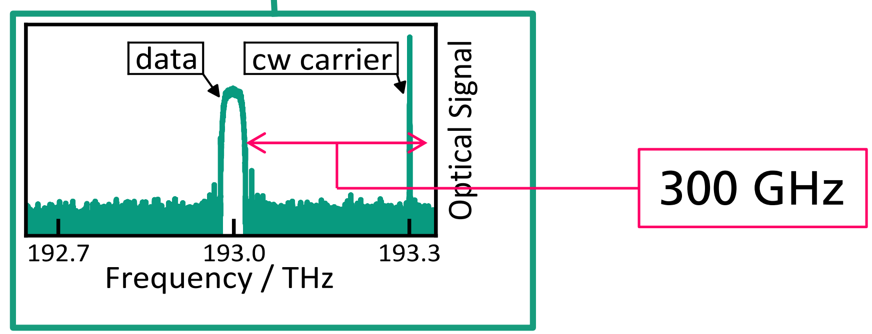
Alternative setup: 100 Gb/s transmission using optical upconversion



- Two tones are generated with a frequency separation of ~300 GHz in the C-band to generate a corresponding carrier through a process called ‘photomixing’

- The input power into the THz transmitter determines the radiated THz power



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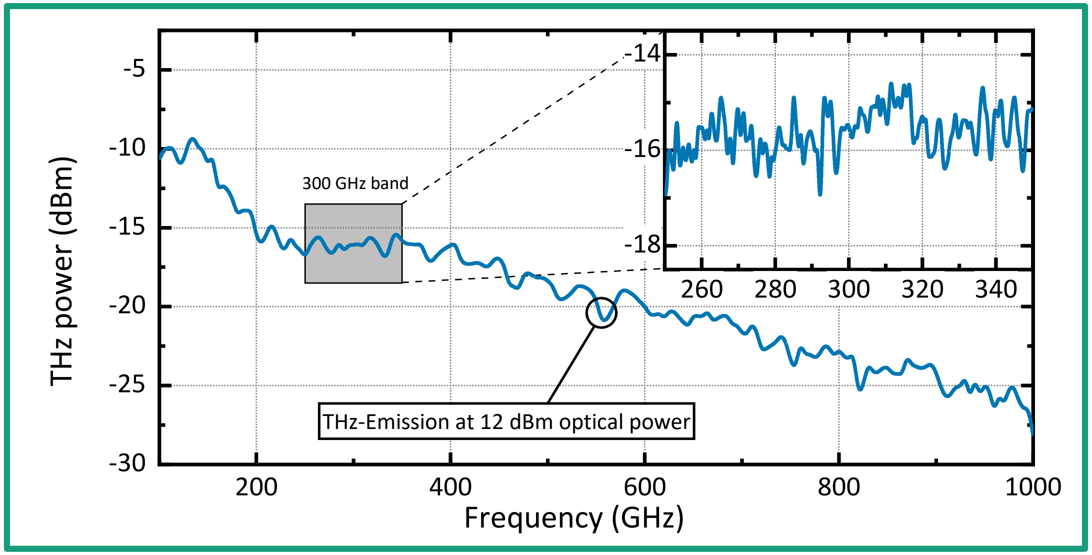
PIN-PD THz emitter
Experimental setup



- Flat frequency response at frequencies around 300 GHz
- Hyper-hemispherical silicon lens couples the THz radiation into free space
- Antenna gain = 21 dBi @ 300 GHz (optical input power: up to 15 dBm)

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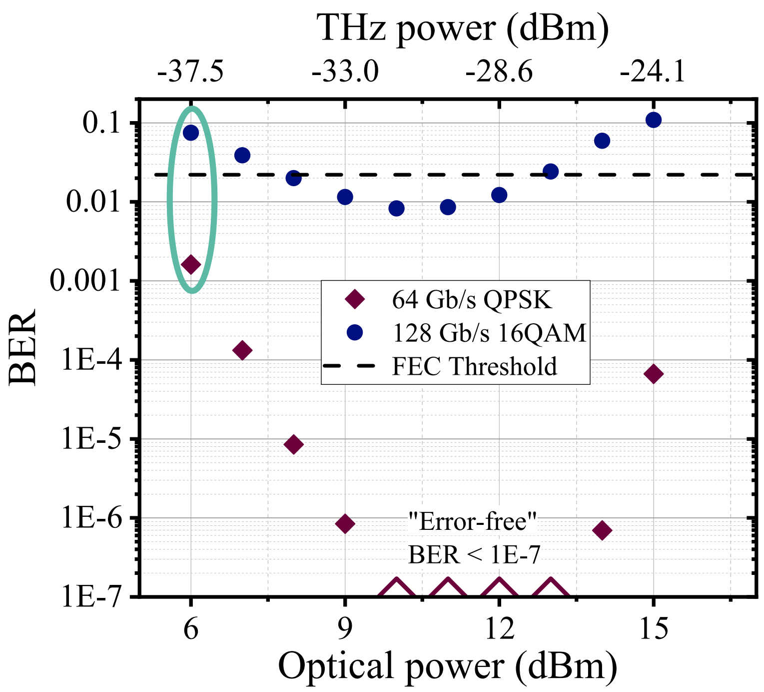
BER performance
100 Gb/s offline experiments: Results

- BER performance of a wireless 64 Gb/s QPSK and 128 Gb/s 16-QAM THz system

- SD-FEC threshold 2.2E-2:
  Net rates of 50 Gb/s (QPSK) and 100 Gb/s (16QAM)



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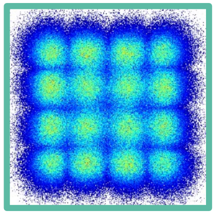
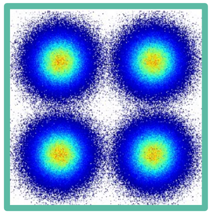
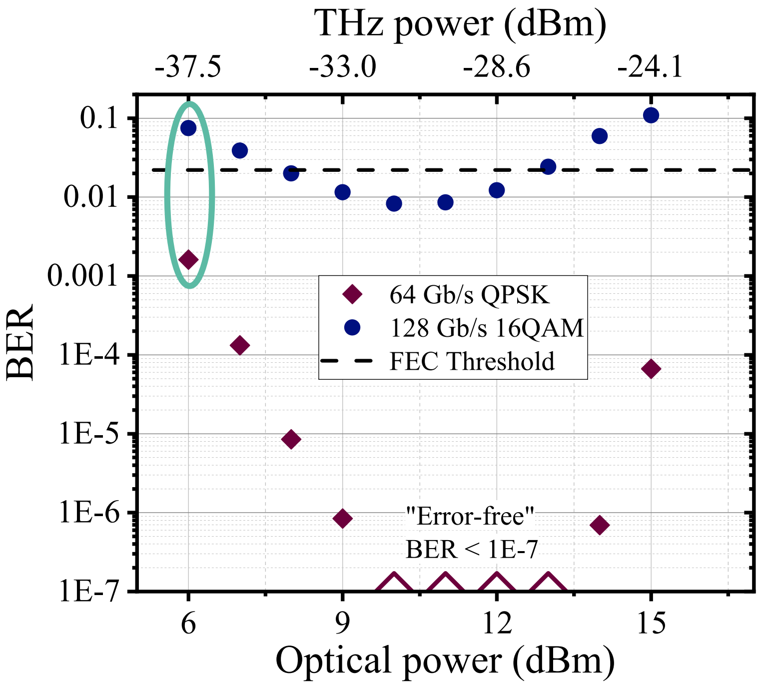
  - Increasing the Rx power does not always translate into better performance
- Three regions: **noise-limited**, optimum, non-linear







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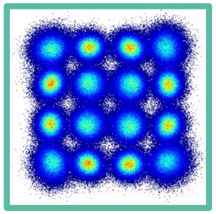

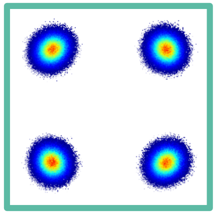

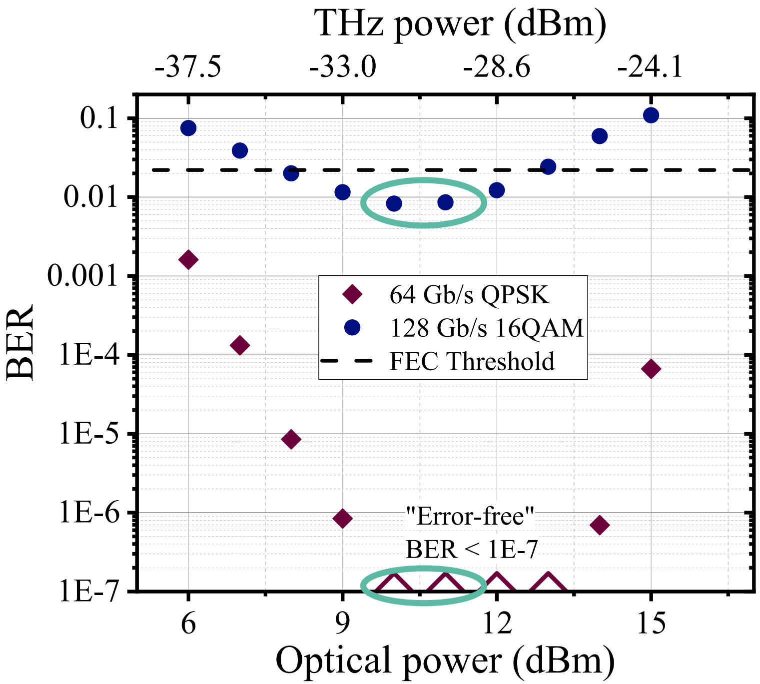

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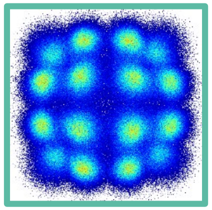

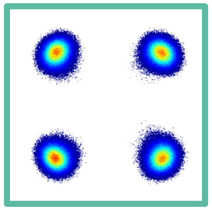

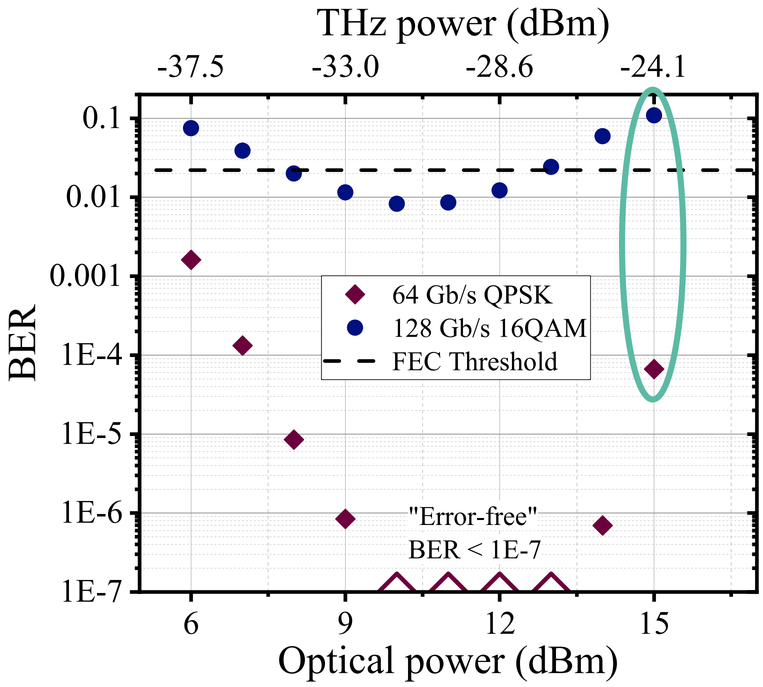

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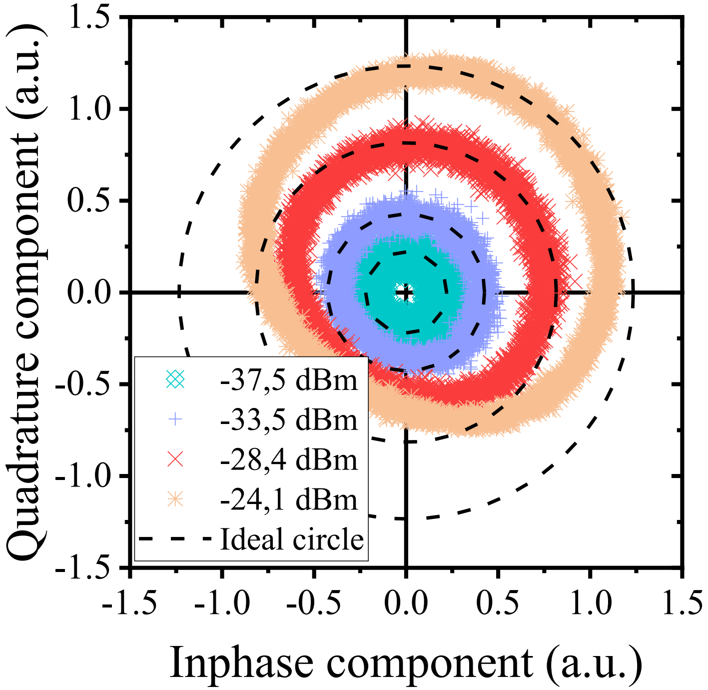
I/Q distortions

100 Gb/s offline experiments: Results

- The assumption that the performance worsens due to non-linearities is further investigated
  - Modulation is turned off → unmodulated THz carrier
- Some non-linear compression can be observed at high received THz power levels
  - Distortion of the circular shape
  - Symmetric compression of the signal
- Improved component linearity required to support higher-order modulation formats



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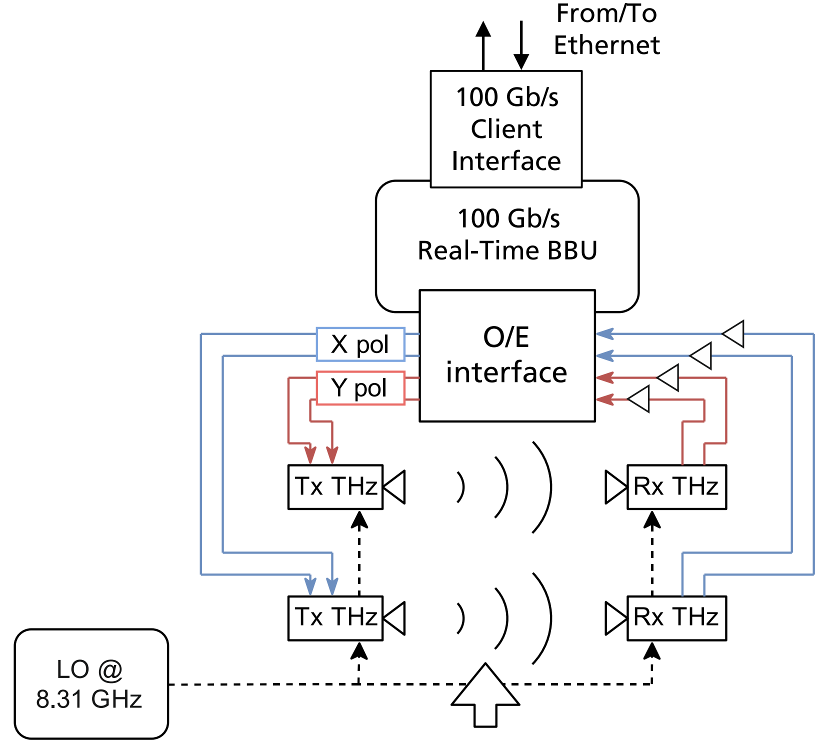
2x2 MIMO setup
100 Gb/s real-time THz wireless transmission

- Fibre-optical BBU, originally designed for 34 GBd PDM-QPSK, is used for a THz wireless link
- To carry the 34 GBd PDM-QPSK data over a 50 cm-long wireless link, two pairs of Tx/Rx THz elements are used
  - Each Tx/Rx pair transports one spatial channel
- The BBU's DSP scheme is a standard approach used for contemporary fiber-based 100 Gb/s and 200 GB/s solutions



Carrier frequency:

8.31 GHz x 36 = 300 GHz

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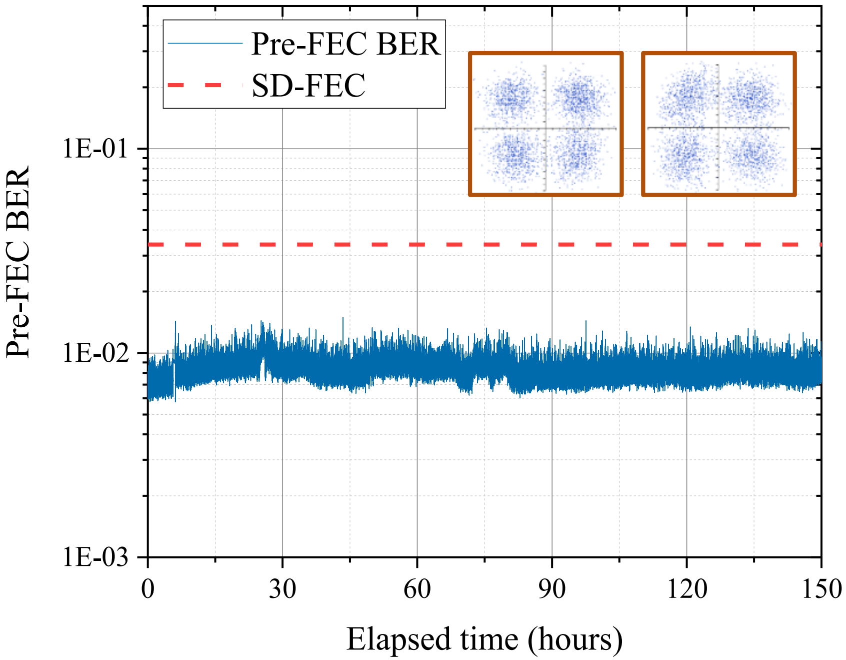
Evaluation of pre-FEC BER
100 Gb/s real-time THz wireless transmission

- Long-term stable (>150h hours) pre-FEC below SD-FEC threshold ($3.4 \cdot 10^{-2}$)
  - 34.34 GBd PDM QPSK
  - 50 cm THz transmission at 300 GHz
  - Mean pre-FEC BER around $8.2 \cdot 10^{-3}$
- During the duration of the experiment, no erroneous bits were found after decoding
  - Error-free transmission ensured by SD-FEC scheme



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Experiments using a 100 GbE traffic generator

100 Gb/s real-time THz wireless transmission

- Latency from BBU (cross-connection + DSP) and THz system: ~8.5 µs *
- Frame loss rate: 1.8 frames per minute (0.03 fps) *
- Measured throughput: 86.5 – 98.08 Gb/s (depending on the frame size) *

* This work has been submitted to IEEE Globecom 2019

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Conclusions

Towards high-capacity THz wireless networks beyond 5G

- A wide range of applications can be envisioned for THz wireless links with high capacity and high range, in particular in **hybrid optical-THz wireless networks beyond 5G**

- Experimental demonstrations of **error-free 100-Gb/s THz Wireless Transmission** over 0.5 m
  - Offline: SISO 32-GBd 16QAM offline
  - Real time: 2x2 MIMO 32-GBd QPSK

- Required next steps in order to **increase capacity, range and flexibility**:
  - Use high-gain antennas (55 dBi)
  - Design highly linear, high output power electronic front-ends for larger constellation sizes
  - Adaptive PHY DSP to cope with channel dynamics

- Next research goal: **Use 100 Gb/s real-time THz link demonstrator in real network scenarios**

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Conclusions

Towards the standardization of THz communications

- **Fraunhofer HHI would welcome the formation of a Study Group on THz communications**

- **Objective:** High-capacity (>100 Gb/s) THz links in the range of hundreds of meters within a hybrid optic-THz wireless network scenario

- **Use cases:** Wireless fronthaul/backhaul links to provide an alternative point-to-point link in case fiber deployment is too complicated/expensive due to the terrain's characteristics

- **Technical SotA:** Stability and technical feasibility of THz transmission link has been experimentally demonstrated for high-capacity data transmission (>100 Gb/s)

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WE PUT SCIENCE INTO ACTION.

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