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

Vienna, Austria – 16.07.2019

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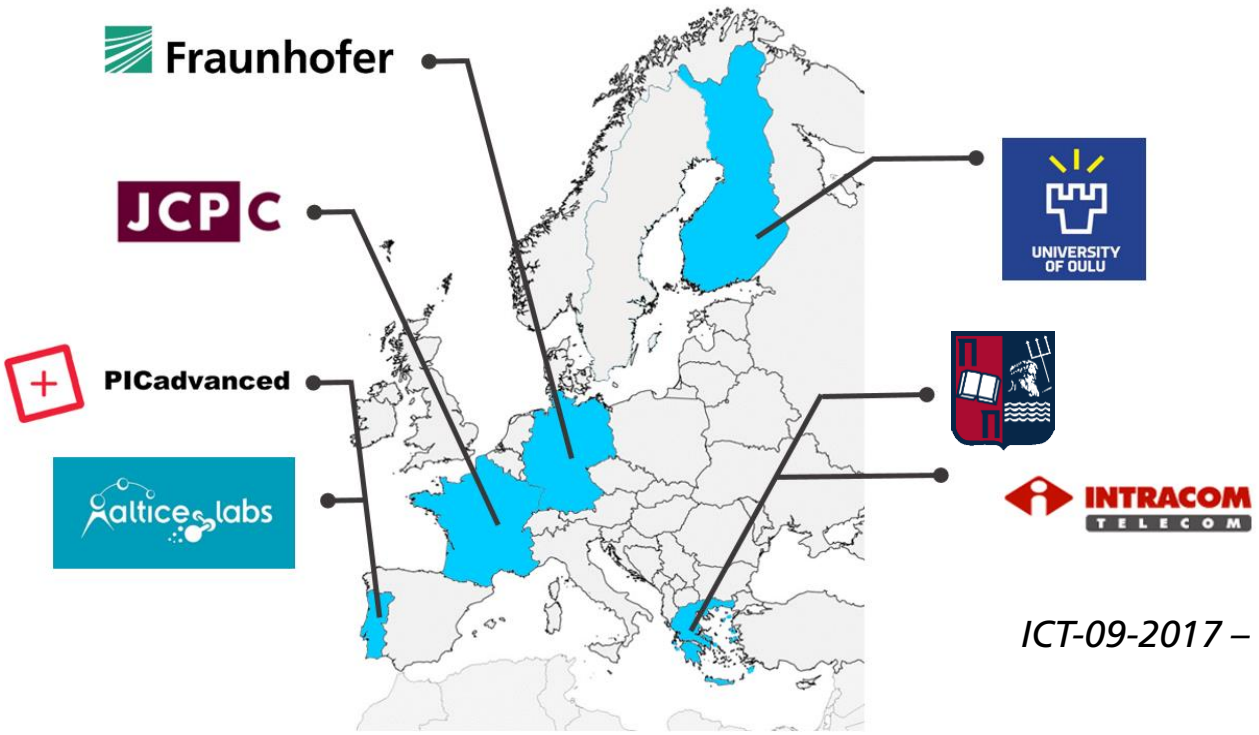
H2020 EU TERRANOVA: *Terabit/s Wireless Connectivity by TeraHertz innovative technologies to deliver Optical Network Quality of Experience in Systems beyond 5G*



TERRANOVA

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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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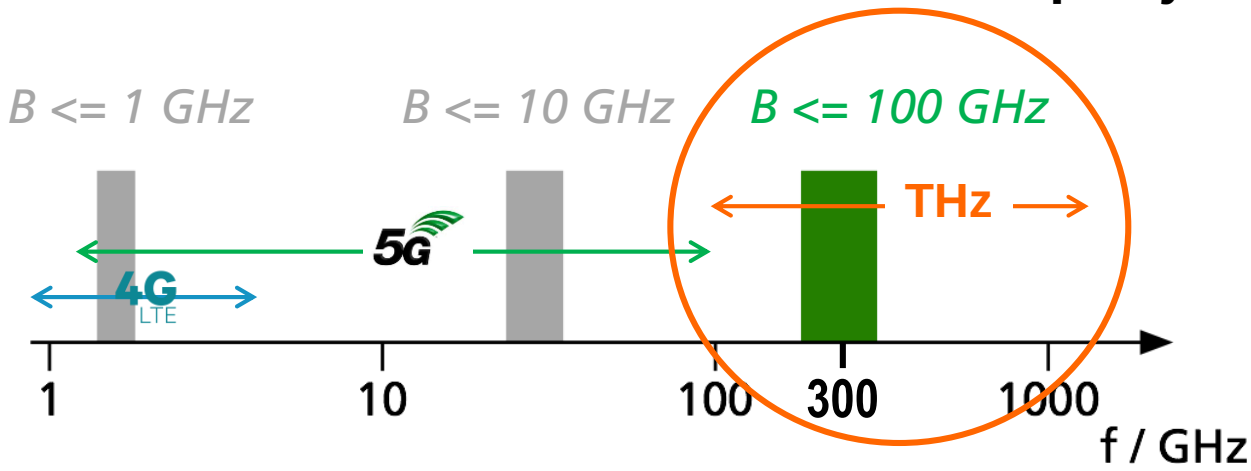
Motivation

- *THz wireless data transmission at carrier frequencies in the 100 – 500 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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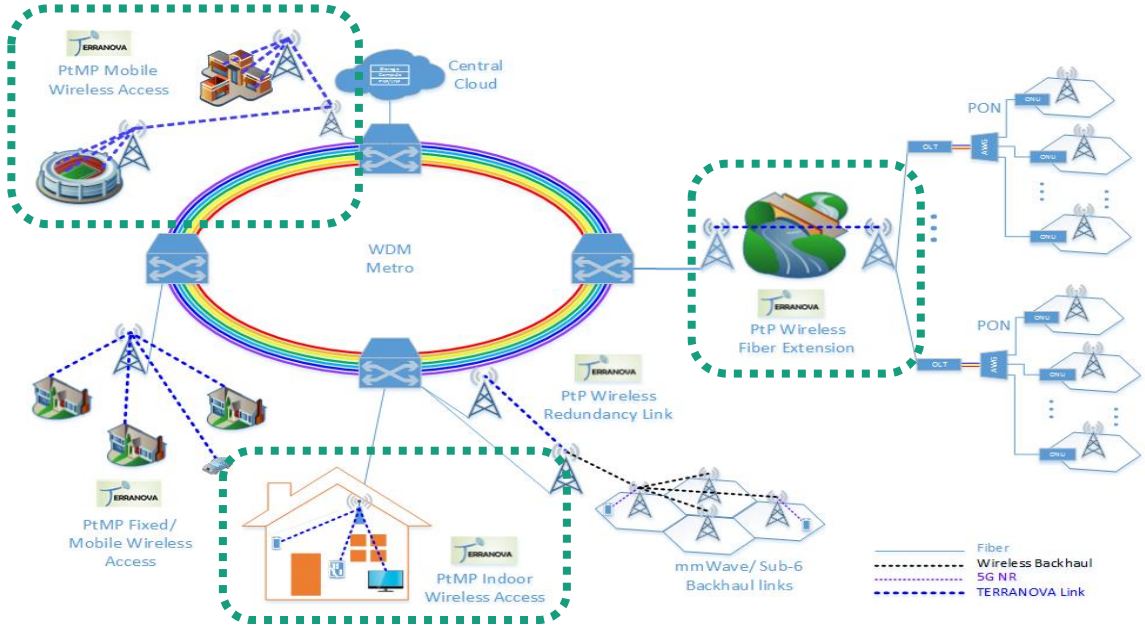
Applications for hybrid optical-THz wireless networks



- *Applications can be classified in 3 generic technology scenarios:*
  - *Point-to-Point (PtP)*
  - *Point-to-Multi-Point (PtMP)*
  - *Quasi-Omnidirectional*
- *We will focus on PtP in this talk*

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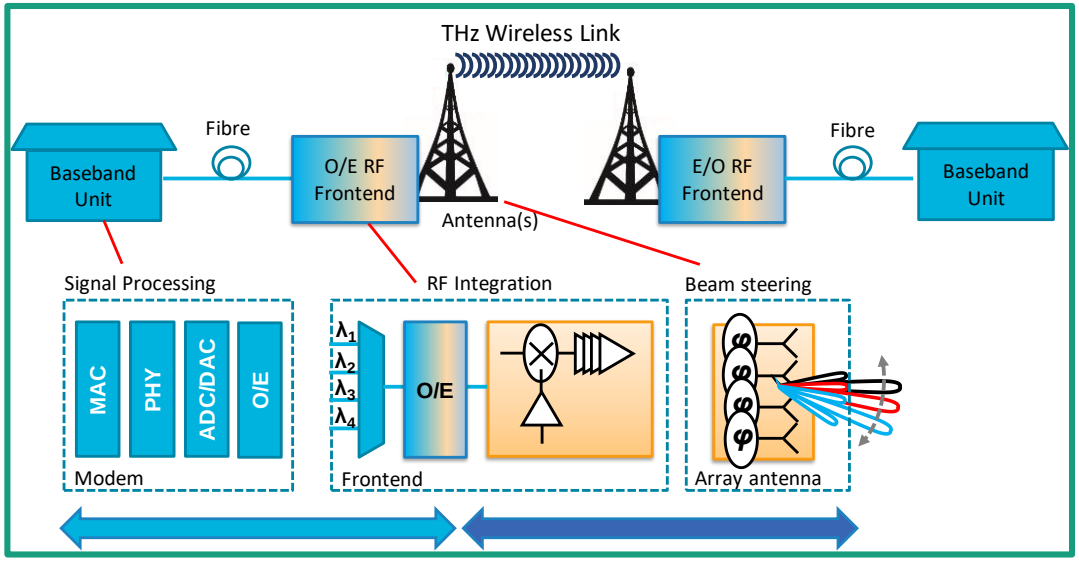
Hybrid optical-THz wireless PtP Links



- **Co-integration of optical frontends and THz frontends** *allows seamless interconnections between legacy fibre infrastructure and THz wireless links*
- *Baseband unit performs* **joint impairment mitigation for hybrid link**

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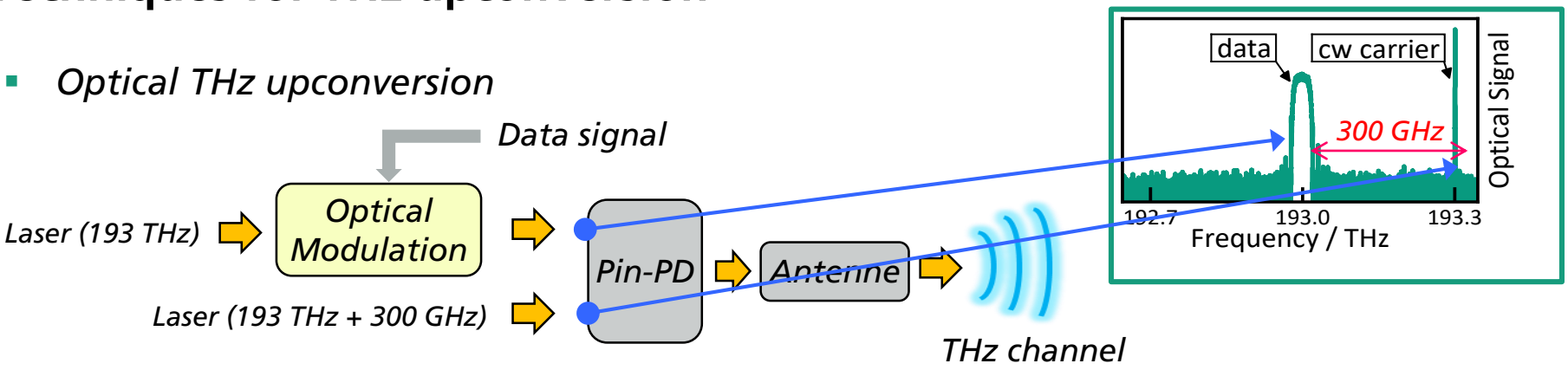
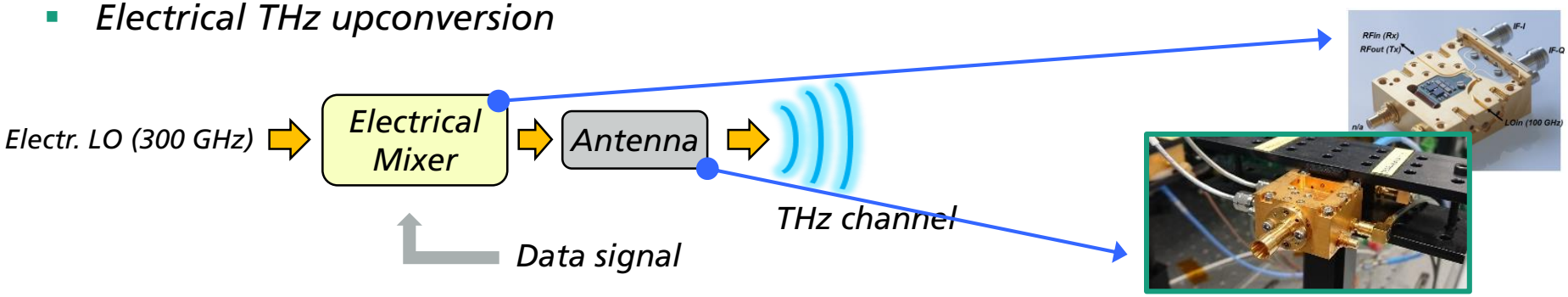
Techniques for THz upconversion

- *Optical THz upconversion*



- *Electrical THz upconversion*



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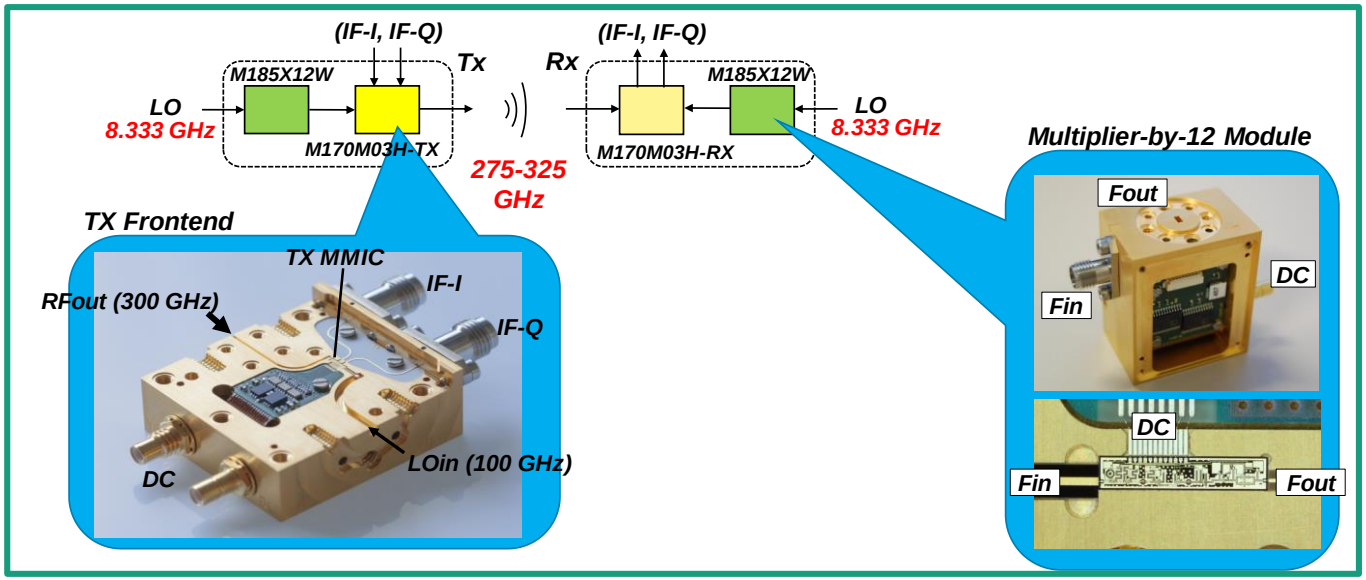
275-325 GHz THz frontend waveguide modules (Tx/Rx)



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

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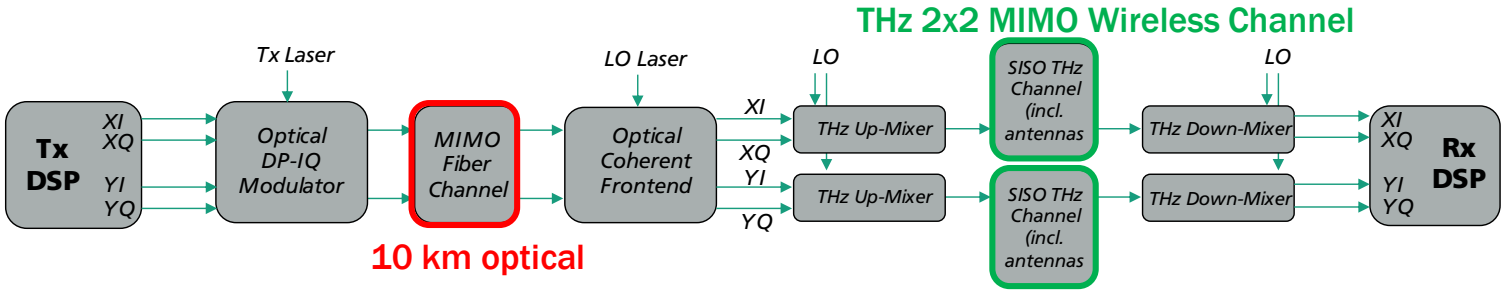
Hybrid optical-THz wireless link simulations



Simulation Parameter	Value
Symbol rate	32 GBd
THz transmit power	-14 dBm
Optical transmit power	-3 dBm
OSNR at optical/THz interface	36 dB
Optical laser linewidth	100 kHz
Optical frequency offset	[-1 GHz ... 1 GHz]
Optical polarization rotation	Full Poincaré sphere
Chromatic dispersion	17 ps/nm/km
Optical link length	10 km
THz phase noise	Measured values
THz frequency offset	[-100 MHz ... 100 MHz]

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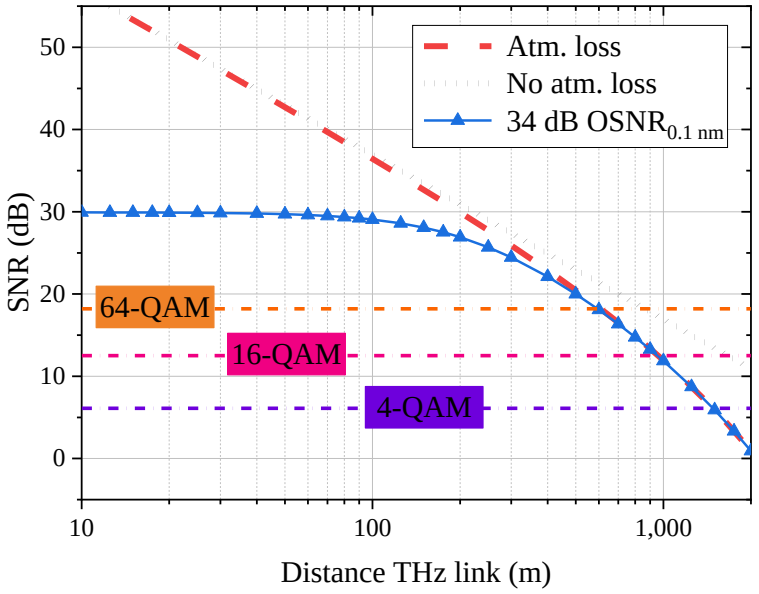
Hybrid optical-THz wireless link simulations

- *For the most part, the overall SNR of the hybrid optical-THz wireless will be determined either by the THz link or by the optical link.*
- *Based on SNR estimations, wireless transmission over 800 m can still be achieved with 16-QAM at this transmit power*
- *Can we use a single DSP for joint mitigation of impairments from the optical and the THz link?*

-14 dBm THz Tx power / 55 dBi antennas



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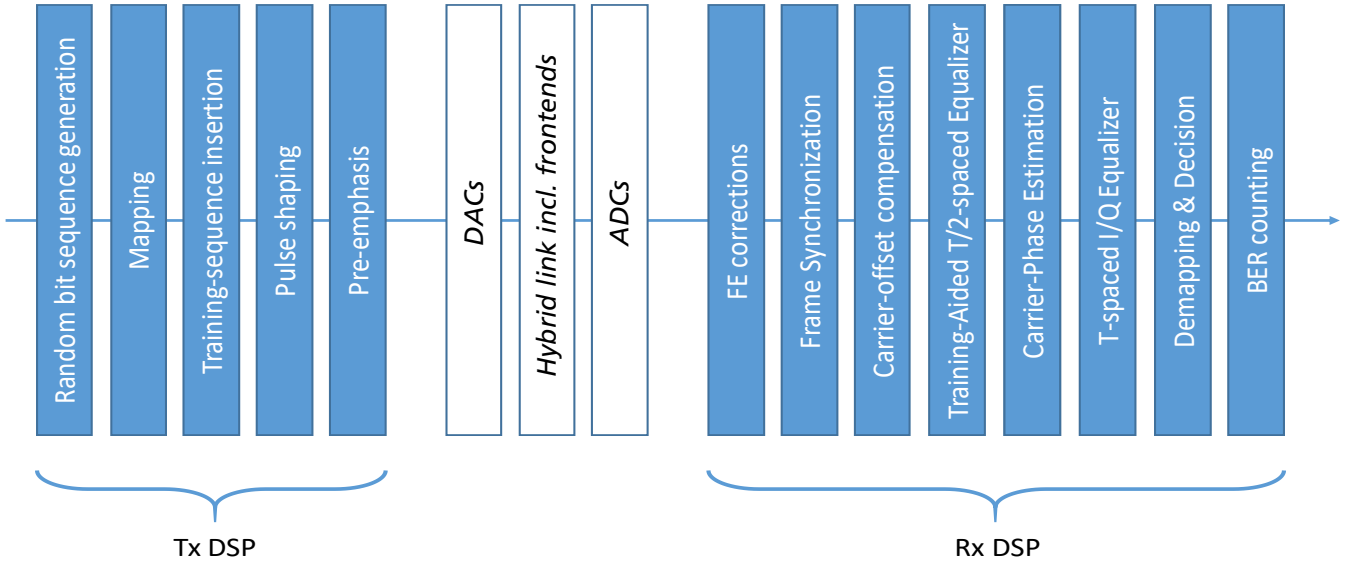
DSP Algorithms and Modem Functions



- *THz PtP LoS channel is very similar to fibre-optical channel*
- *Typical single-carrier PHY DSP for optical channels can also be used for THz PtP LoS channel (but additional adaptivity required)*, **as well as for the combined fibre-optical / THz-wireless channel**

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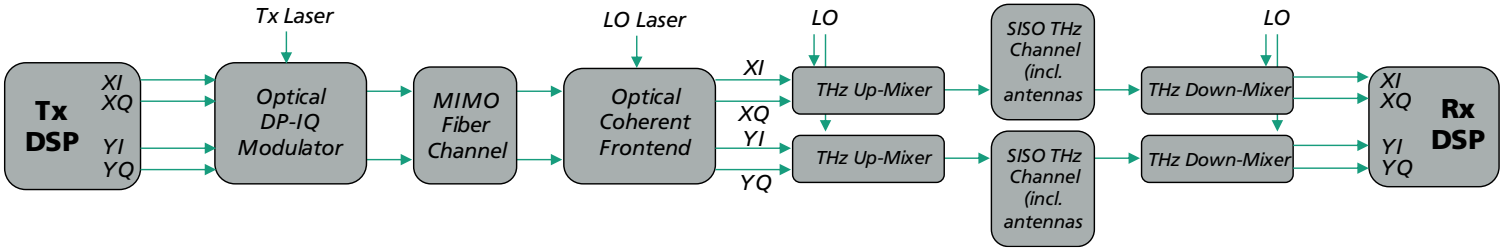
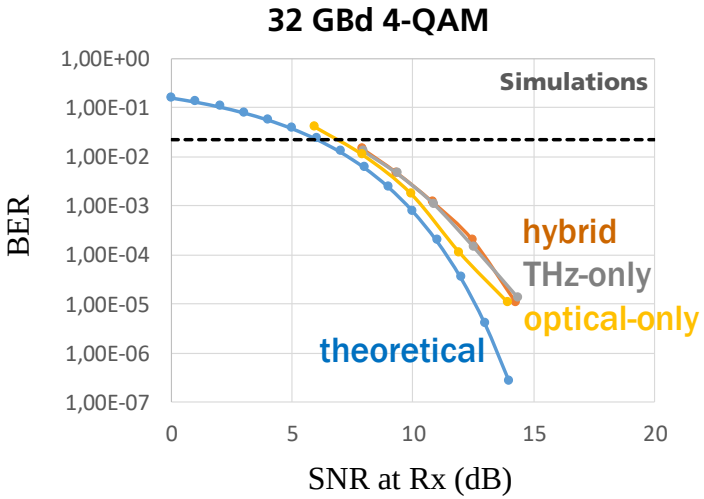
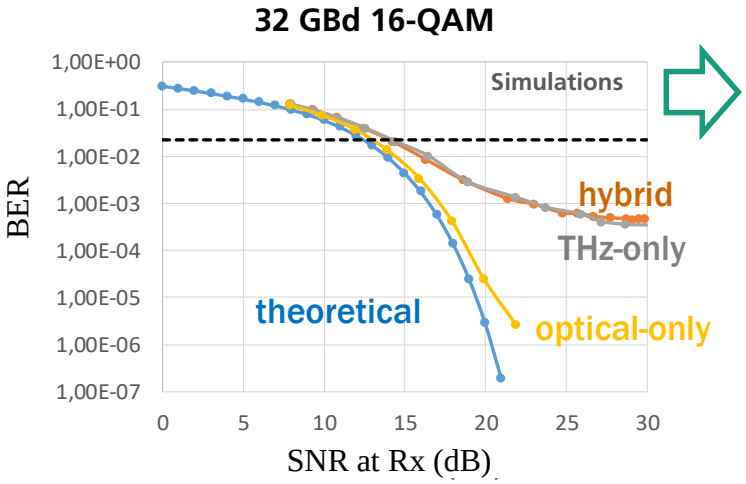
Joint impairment mitigation for hybrid optical-THz Links







Hybrid channel seems to be limited by transmission impairments in the THz link

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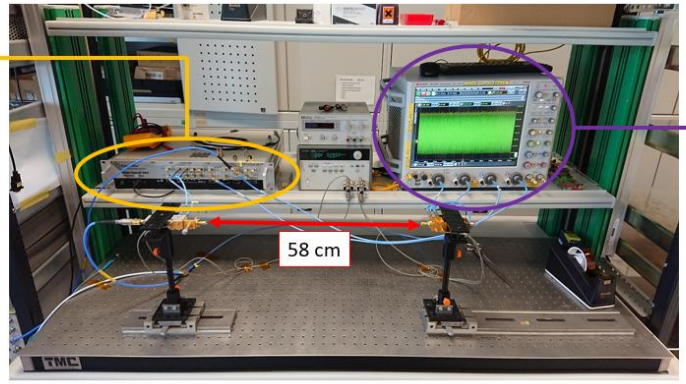
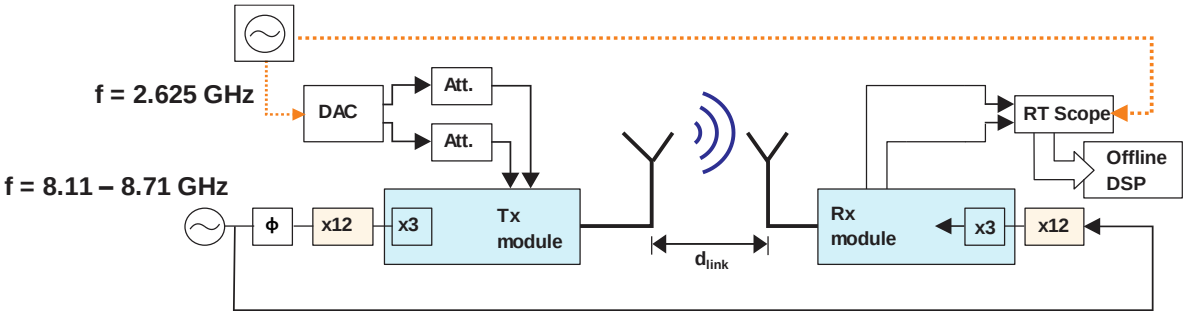
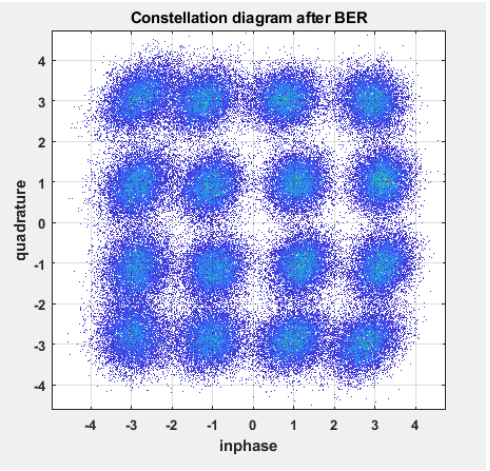
All-electronic 100 Gb/s THz wireless transmission experiment (offline)



300 GHz carrier / 23 dBi antennas

- *32 Gbaud – 16 QAM*
- *Raw 128 Gb/s @ BER = $1.1 \cdot 10^{-2}$*
- *Net 100 Gb/s FEC-corrected*





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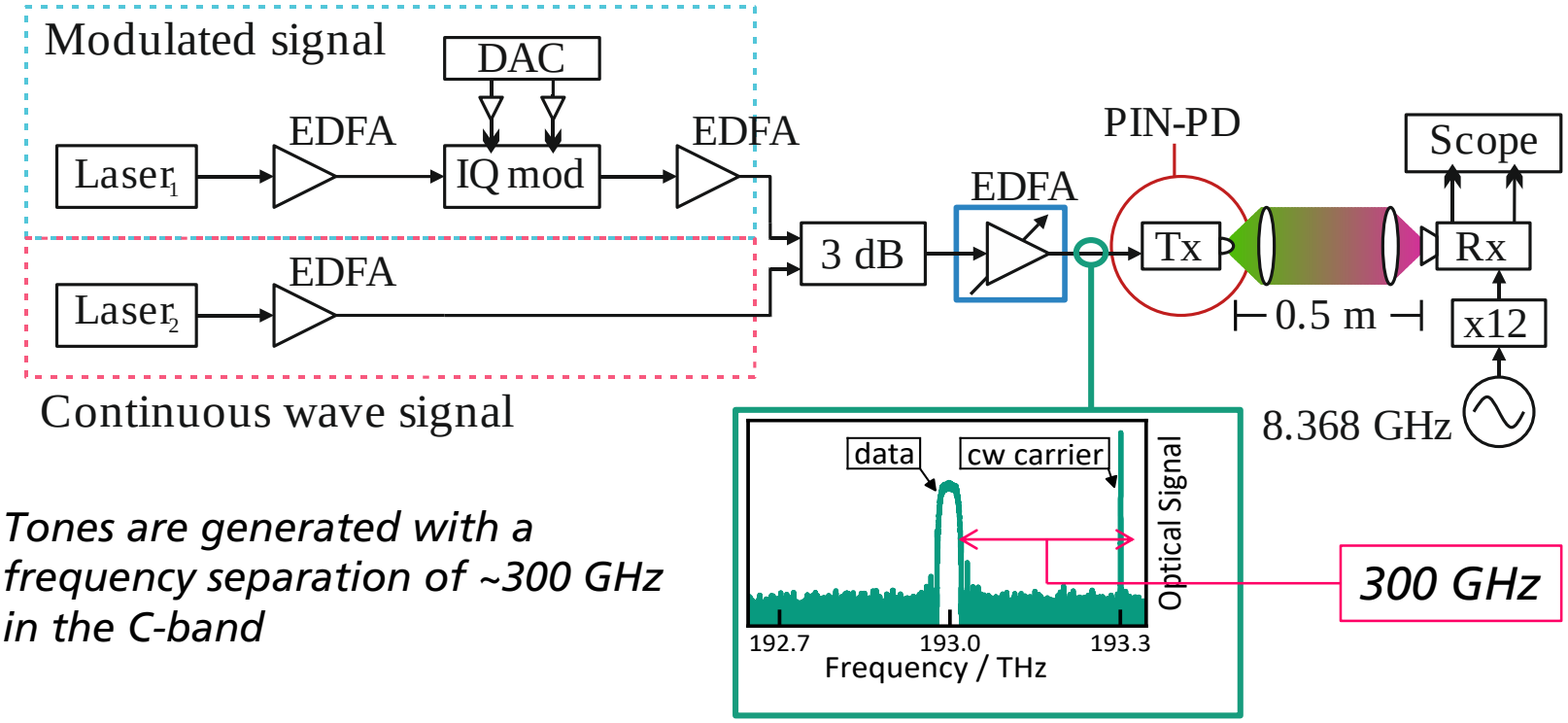
Alternative setup: 100 Gb/s transmission using optical upconversion



- *Tones are generated with a frequency separation of ~300 GHz in the C-band*

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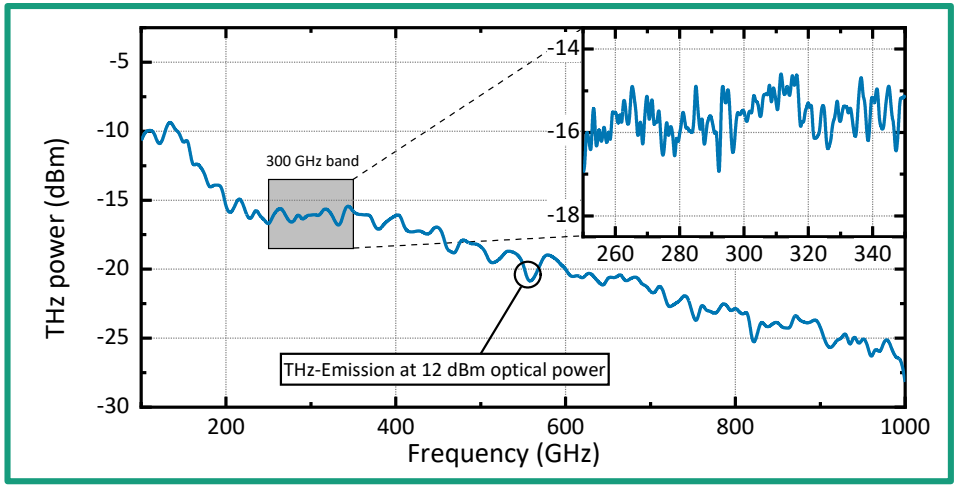
PIN-PD THz emitter

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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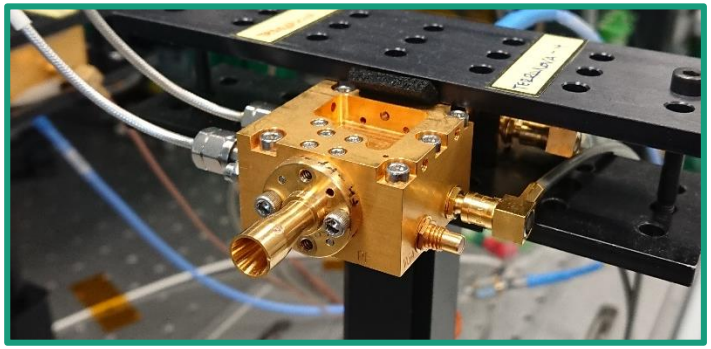
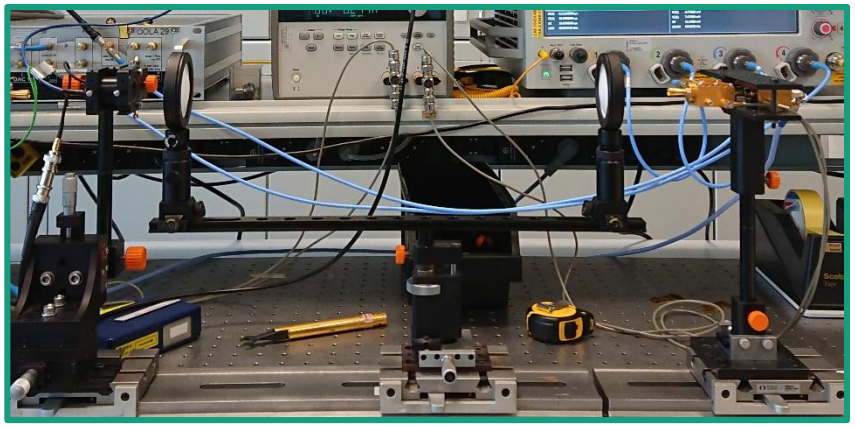
THz receiver and complete setup

Experimental setup





- *~50 GHz bandwidth centered around 300 GHz*
- *Horn antenna*
- *Antenna gain = 23 dBi @ 300 GHz*

- *Experimental setup with lenses between THz emitter and THz Rx*

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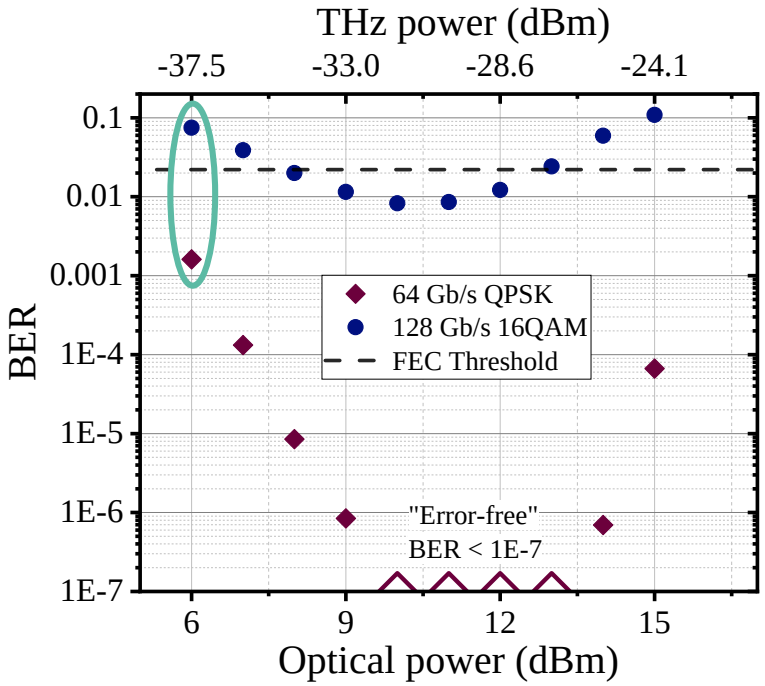
BER performance

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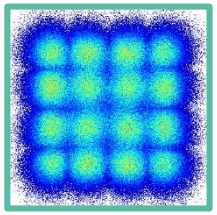
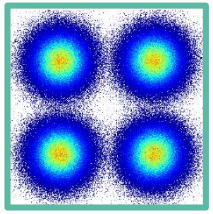
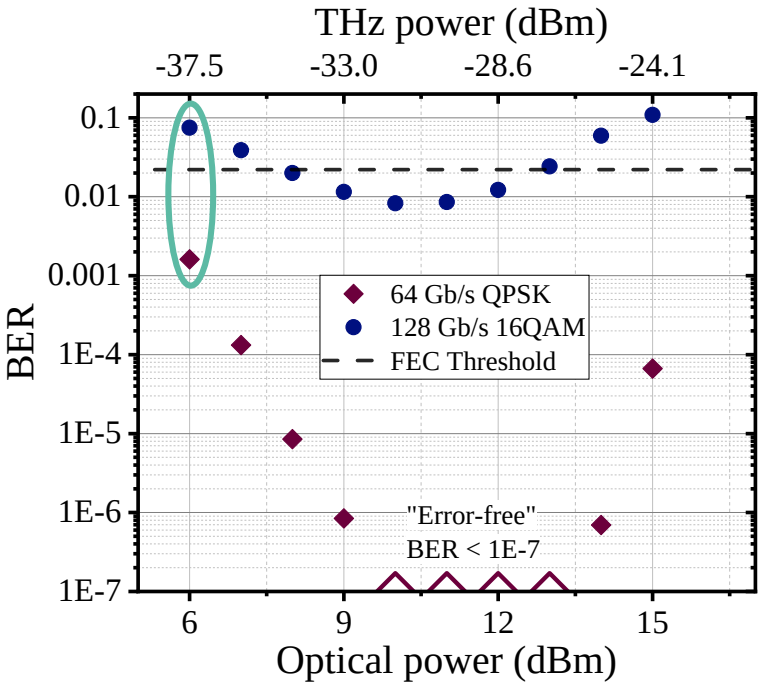
- *Non-monotonic behavior:*
  - *Increasing the Rx power does not always translate into better performance*
- *Three regions:* ***noise-limited****, optimum, non-linear*







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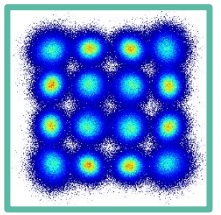

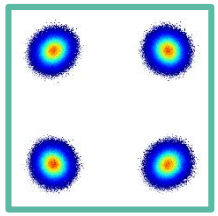

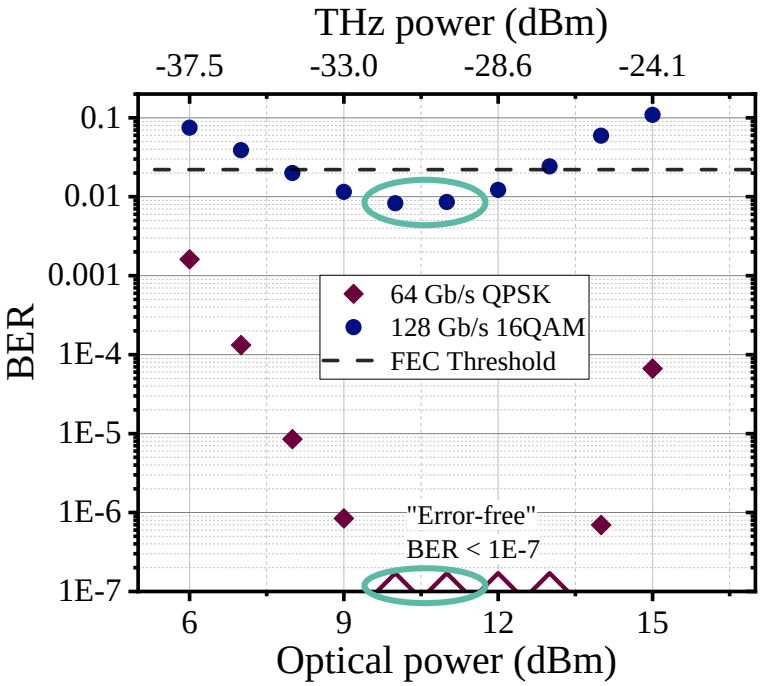

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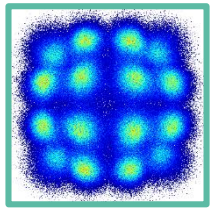

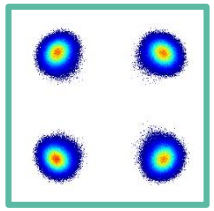

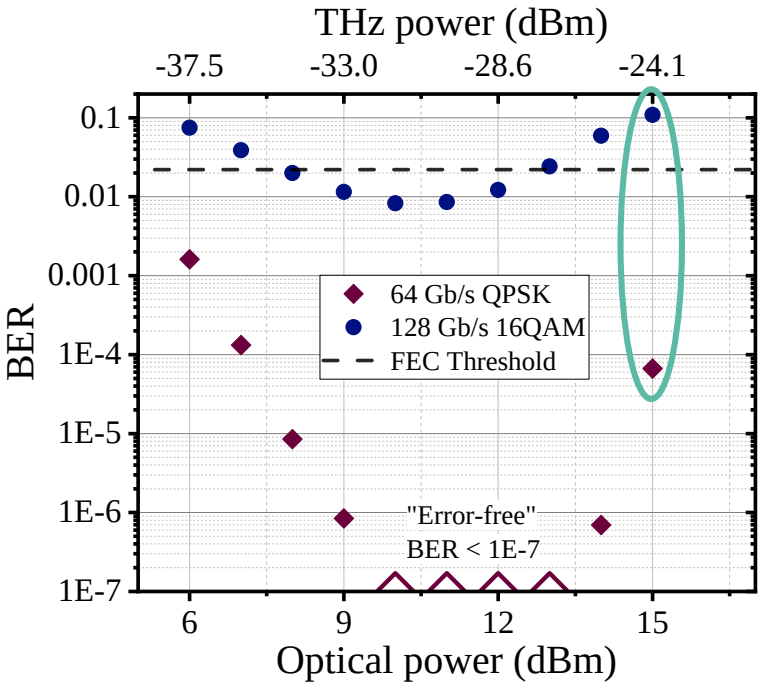

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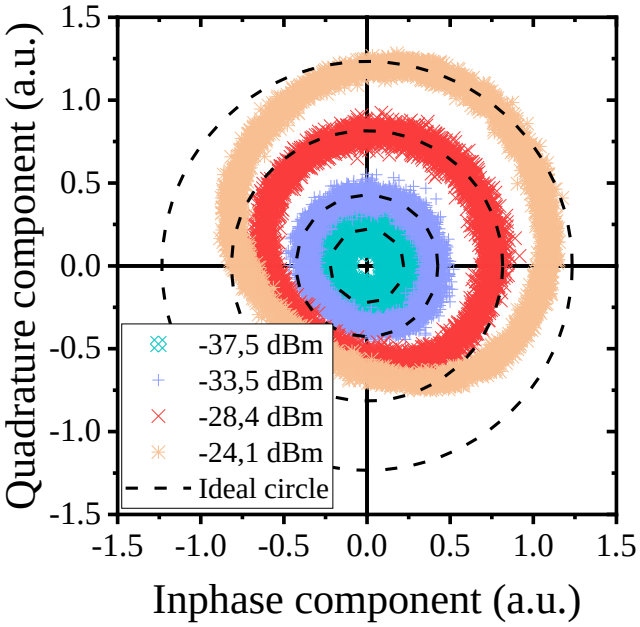
I/Q distortions

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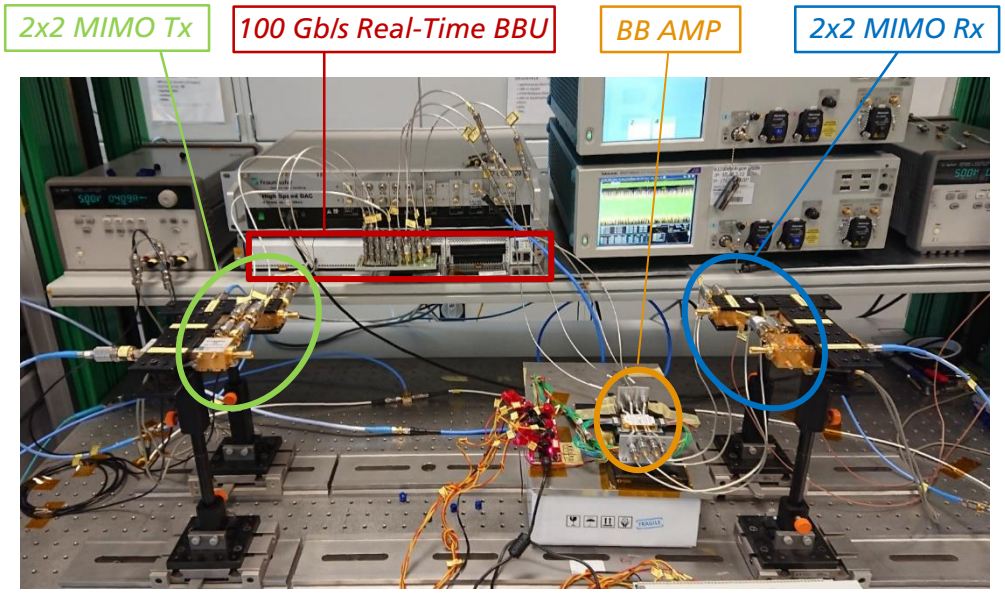
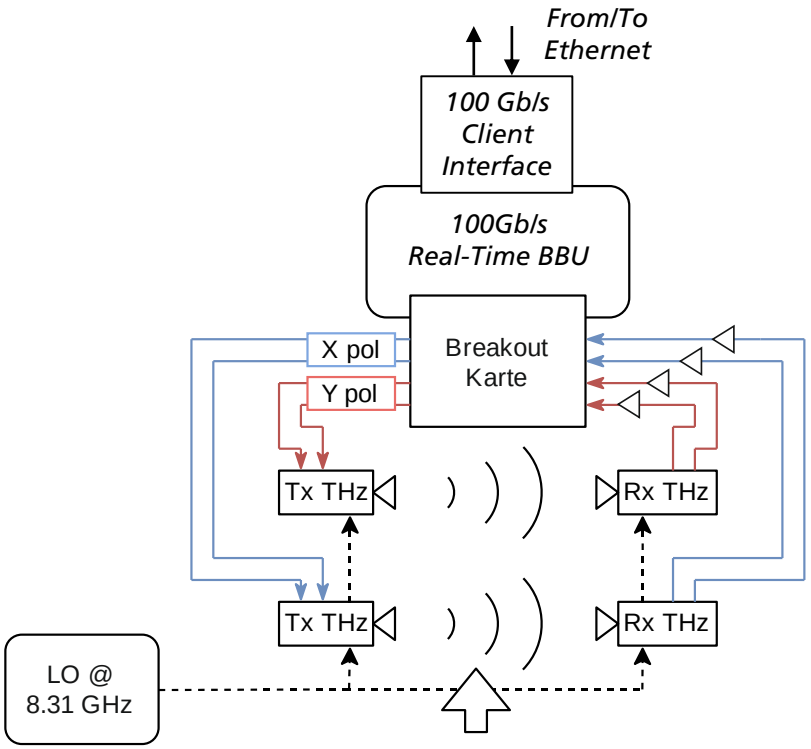
2x2 MIMO setup
100 Gb/s real-time THz wireless transmission



- *Fibre-optical BBU, originally designed for 34 GBd PDM-QPSK, is used for a THz wireless link*



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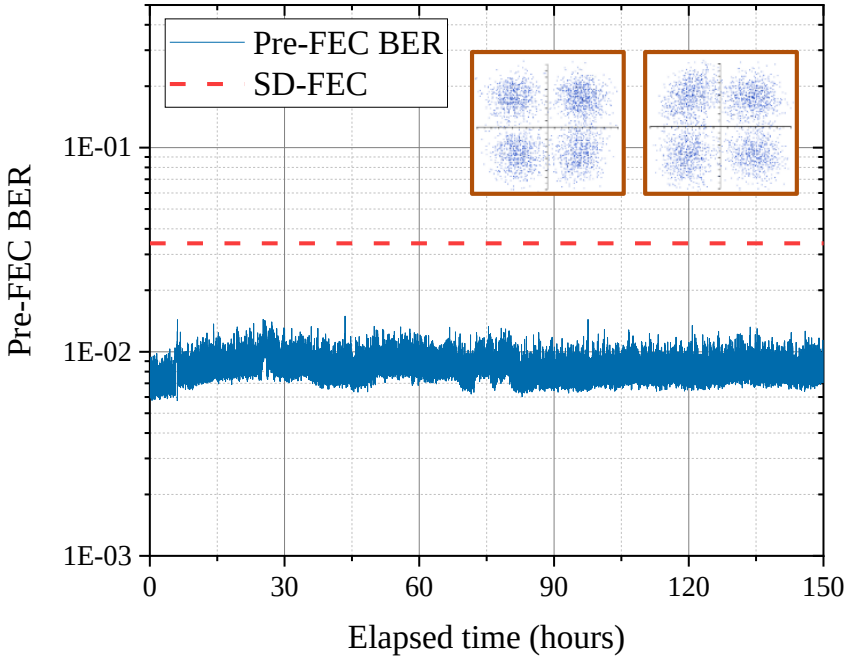
Evaluation of pre-FEC BER
100 Gb/s real-time THz wireless transmission

- *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 $8.2 \cdot 10^{-2}$*
- *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 hybrid optical-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**
- *Simulations indicate* **potential for >100 Gb/s capacity over ~ 1 km** *in such links*
- *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 hybrid optic-THz communications

- **Fraunhofer would support 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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Fraunhofer Institute for Telecommunications, Heinrich Hertz Institute, HHI

WE PUT SCIENCE INTO ACTION.

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