Can we transfer analogue coherent optics of access networks to the realm of datacenters?

ECOC 2019
7th Int. Symposium for
Optical Interconnect in Data Centres
Dublin ~ Sept. 24th, 2019

Bernhard Schrenk

AIT Austrian Institute of Technology

Presentation Outline

Low-Cost Coherent
- Intradyne? Heterodyne?
- Homodyne!

Graceful Migration from IM/DD to Coherent
- Analogue Coherent Optics
- Coherent TDMA

An Experimental Coherent Pod
- Locking a CRX to free-running TX
- Locking fast!

"Bring quantum communication into data centres"
- Coherent for Quantum Comms

Wrapping up
- Conclusions
- Further considerations

AUSTRIAN INSTITUTE OF TECHNOLOGY

Low-Cost Coherent

EML as Coherent TRX

Coherent TDMA

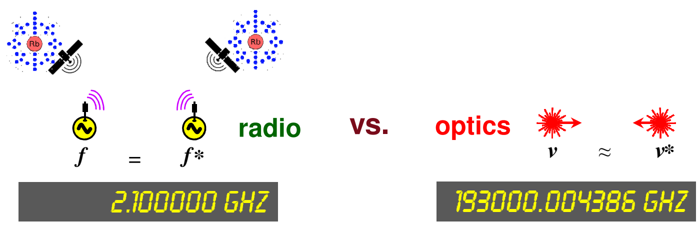
“Bring quantum communication into the data centers”

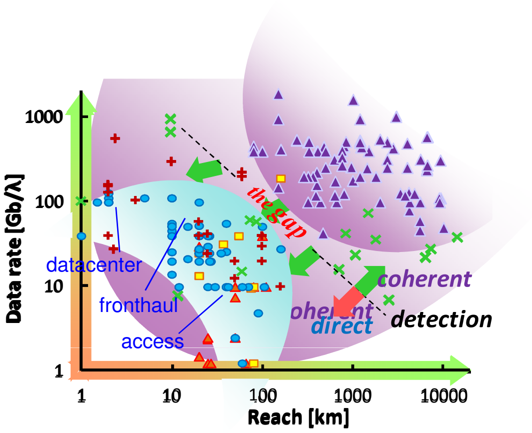
Conclusions

AUSTRIAN INSTITUTE OF TECHNOLOGY

Coherent?

Yes!





E. Armstrong (1918):
„superhet“ receiver,
today virtually everywhere

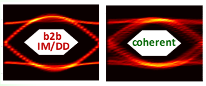
+100 years

today (2019):
direct photodetection
in many segments

→ eliminating the performance gap **Direct ↔ Coherent** detection solves pressing problems
– yet it needs to satisfy requirements for the transceivers in terms of cost and energy consumption

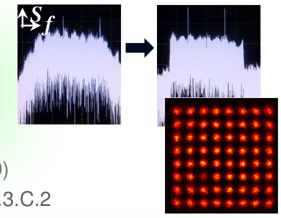
Component of Choice: The EML

Coherent TRX
- homodyne
- analogue, no DSP
- full-duplex



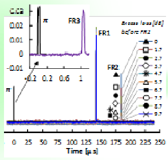
B. Schrenk et al., JLT **37**, 555 (2019)

Analogue Radio-over-X
- high signal integrity
- no DSP, full-duplex

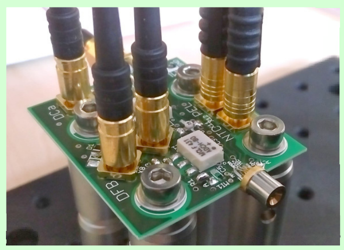


B. Schrenk, JLT **37**, 2866 (2019)
B. Schrenk et al., ECOC'19, Tu.3.C.2

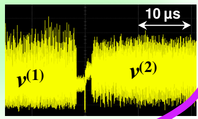
OTDR
- detect reflections
- high accuracy (ranging + magnitude)



B. Schrenk et al., OFC'19, M4G.2

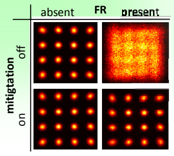


Packet-Level Coherent RX
- fast locking (< 1 ns)



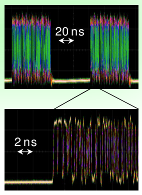
B. Schrenk et al., JLT, in preprint

Spectrally Floating Transmission
- stay locked while hopping
- evade crosstalk
- secure transmission



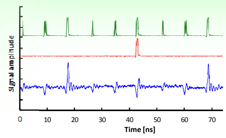
B. Schrenk et al., Opt. Lett. **44**, 2771 (2019)

Fast Optical Gating
- λ blocker in switch



B. Schrenk et al., JLT **37**, 3979 (2019)

Neuromorphic Functions
- frequency-coded neuron



B. Schrenk et al., ECOC'19, P.27

Low-Cost Coherent

EML as Coherent TRX

Coherent TDMA

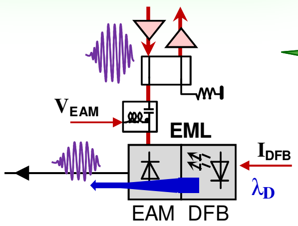
"Bring quantum communication into the data centers"

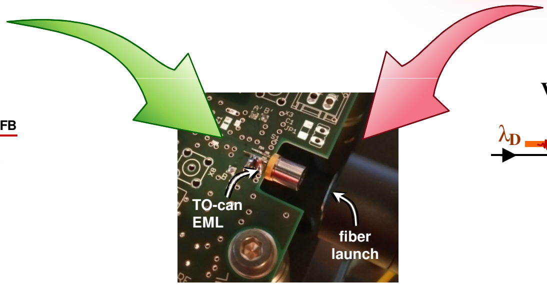
Conclusions

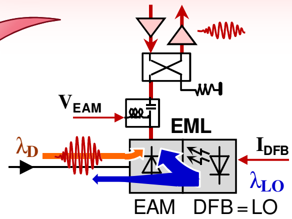
EML-Based Coherent Optical Transceiver

EML as Transmitter
- high-bandwidth (100 GHz)
- energy efficient (65 mV_{pp}/dB)

EML as Coh. Receiver
- **homodyne** reception (injection locking)
- **monolithic** LO integration
- tunable EML optional







B. Schrenk, JSTQE **24**, 3900207 (2018)

Coherent Homodyne Transceiver
- **full**-duplex bidirectional over 1 RF port
- single **TO**-can device (w/ integr. micro-cooler)
- **analogue**, no DSP
- dynamic range: >20 dB at full-duplex 2.5 Gb/s

B. Schrenk et al., JLT **37**, 555 (2019)

Key Characteristics of the EML

▶ **DFB: the LO and TX Seed**

V-L-I: fibre-coupled power of 4.5 dBm at 100 mA bias

▶ **EAM: the Modulator and Photodetector**

T-V: TX extinction of 13 dB at -1.6V bias
RX absorption of ~6 dB at -1V bias

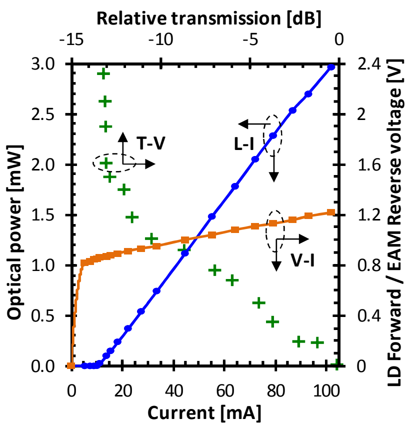
▶ **EML Injection Locking**

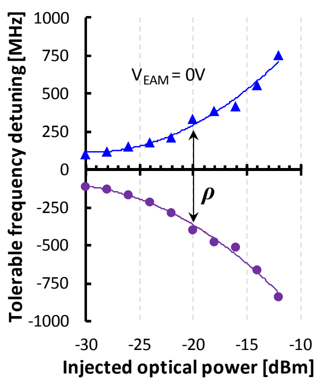
ranges 660 MHz for input power of -20 dBm
210 MHz -30 dBm

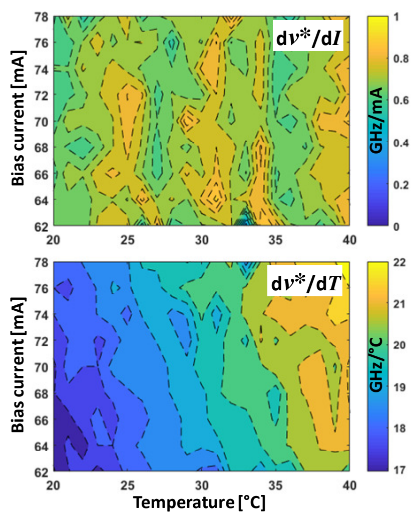
▶ **EML Tunability**

T/o: 12.4 GHz/°C
e/o: 0.54 GHz/mA

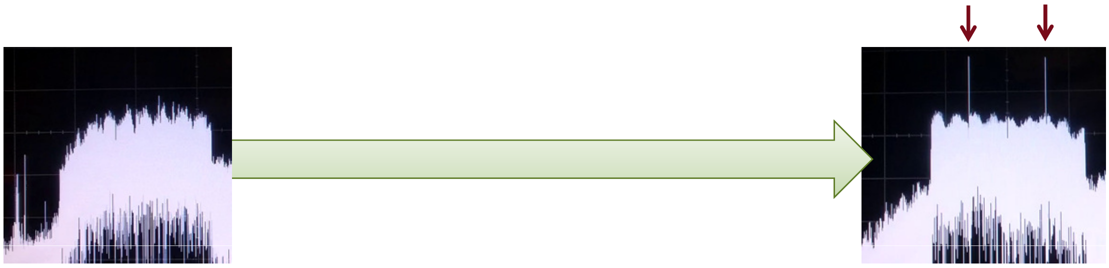
✓ wavelength stability of TEC-controlled EML is well below injection locking range

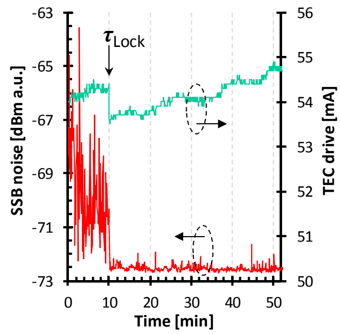






Locking the EML on a Data Signal





- **Locking Stability**

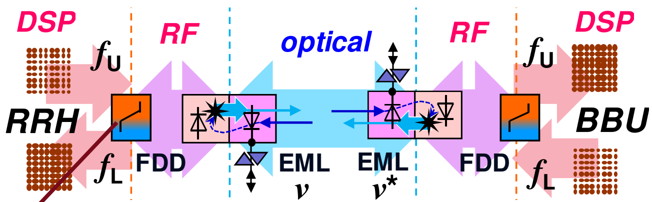
Unlocked coherent reception: beating λ_{RX}(LO) ↔ λ_{TX}
× introduces harmonic in modulation sideband

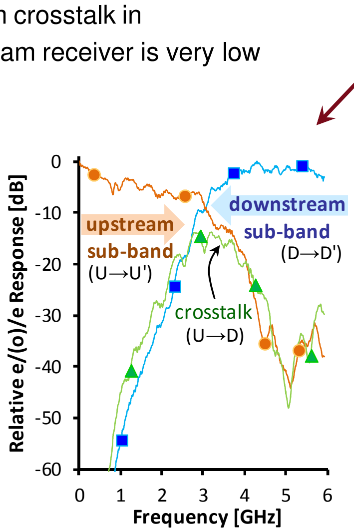
Homodyne (locked) reception: no beating λ_{RX}(LO) ↔ λ_{TX}
✓ translates to minimum sideband power
governed by RIN, EAM dark current, LNA noise

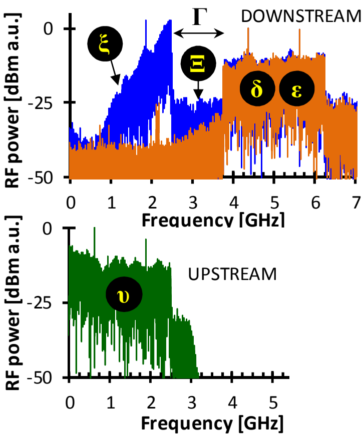
Full-Duplex Coherent TRX

- dual-function EML:
  modulate and detect simultaneously
- directional RF split with electrical FDD

→ upstream crosstalk in downstream receiver is very low







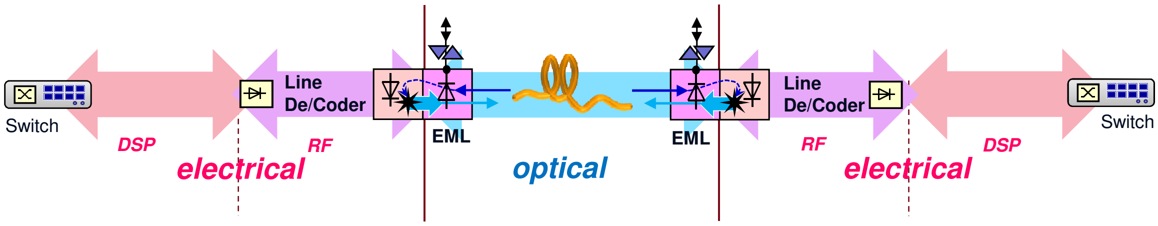
Low-Cost Bidi Coherent Link

State-of-the-Art

× no such solution yet

EML as Coherent Transceiver

- electrical down/uplink duplex
  (e.g., FDD + symbol shaping)
- ✓ “1+1” interface: 1 fiber, 1 RF for entire TRX
- ✓ enables any-to-any and p2mp schemes
- ✓ “better than SFP28”: single T/ROSA



Low-Cost Coherent

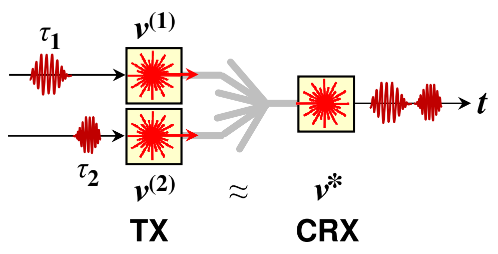
EML as Coherent TRX

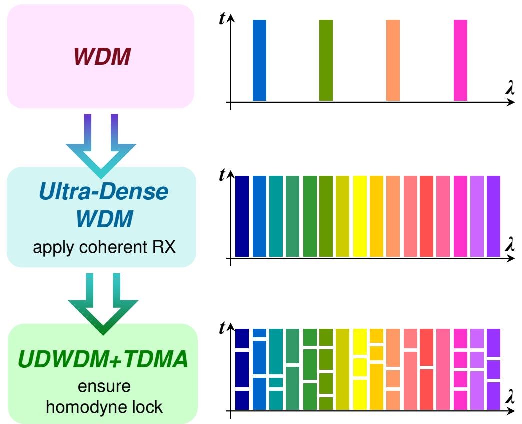
Coherent TDMA

“Bring quantum communication into the data centers”

Conclusions

Coherent WDM under TDMA

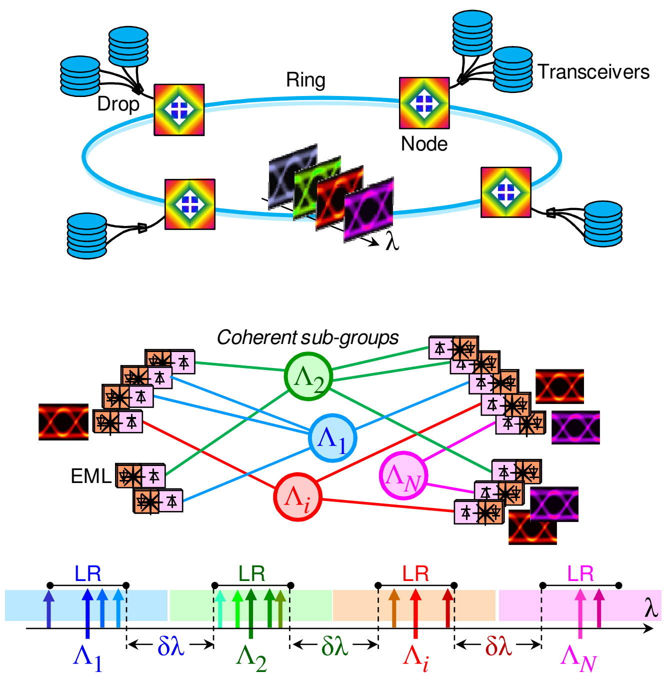




Introduction of TDM operation

- ▶ coherent reception needs to adapt to TDMA mode
- ▶ free-running transmitters:
  coherent homodyne reception has to comply with fast locking

Coherent Homodyne Datacenter Network



Pod with Ring + Tree Topology

- ▶ ToR switches connecting to multiple end-hosts
- ▶ Physical topology of a ring, however, logically a mesh that enables any-to-any communication

- ▶ Coherent sub-groups are collapsed over the pod, allowing virtual point-to-multipoint links
- ▶ resource-friendly allocation: TDMA → mice do not spectrally exhaust the pod network

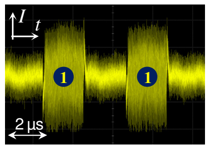
Coherent Homodyne Datacenter Network

Experimental Coherent Network

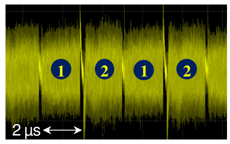
- 2 free-running TO-can EML transmitters
  TDMA frame rate: 240 kHz, guard interval: 140 ns
- 1 TO-can EML as coherent RX
- Network load at first ring hop

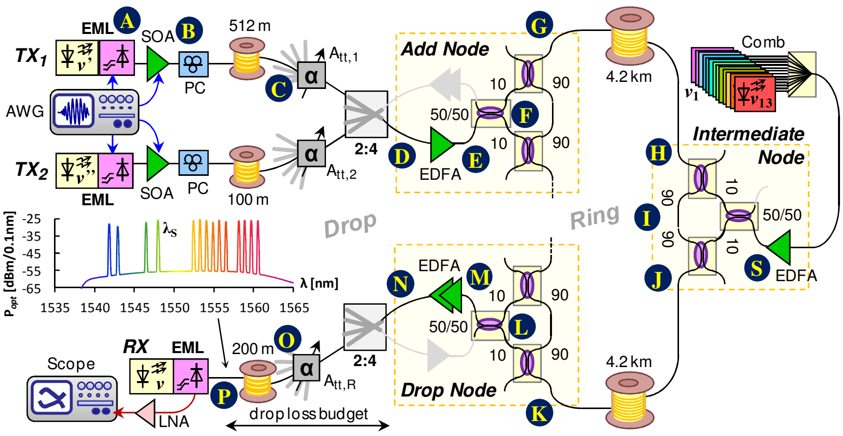
Received signal

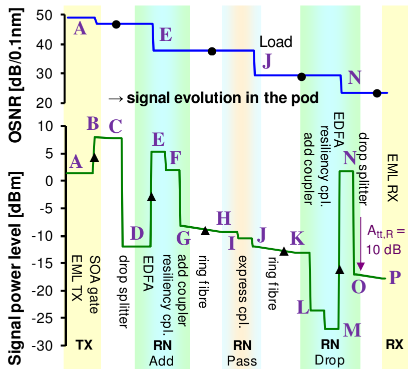
1 TDM channel:



2 TDM channels:



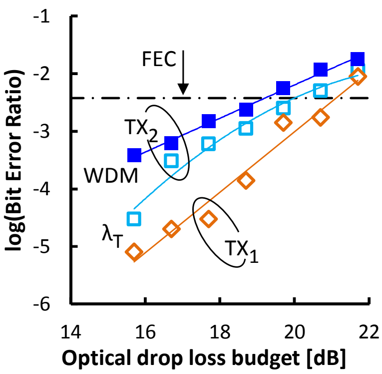


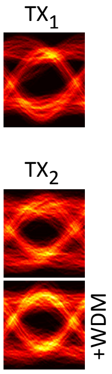


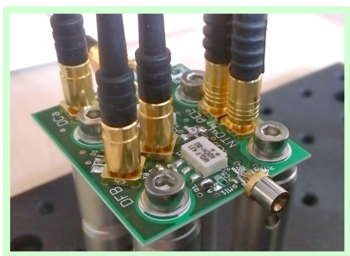
Coherent Homodyne Datacenter Network

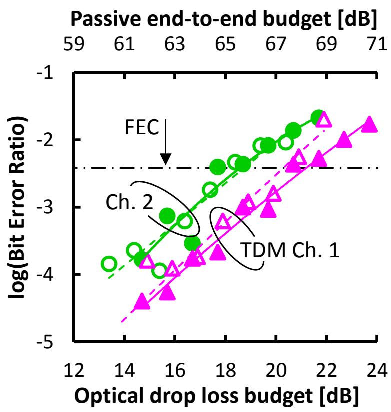
Coherent Reception Performance

- exploiting the full TO-can EML bandwidth of ~7.3 GHz
- locking correct performed for set packet timing and robust to WDM side-channels
- correct locking on both channels: coherent homodyne reception of free-running transmitters
- filterless pod with 1:32 drop split, 9 km ring reach feasible









- no TIA co-integration yet: current results are for EML+LNA

Low-Cost Coherent

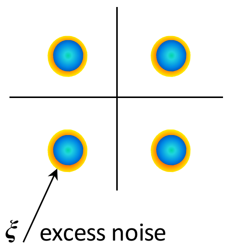
EML as Coherent TRX

Coherent TDMA

"Bring Quantum Comm into data centers"

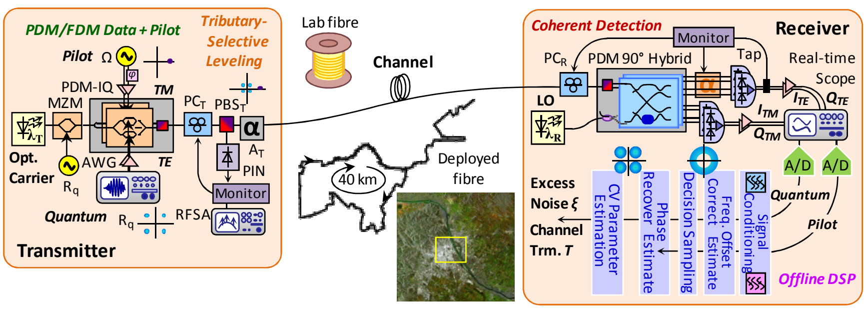
Conclusions

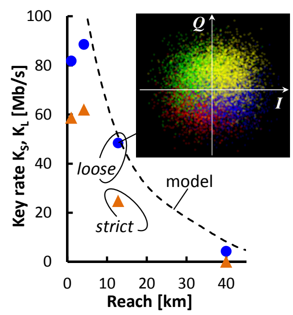
Coherent for Quantum Communication



CV-QKD with access-grade components

- exploits the Heisenberg uncertainty of highly attenuated coherent states to securely generate random keys
- overlaps with telecom reception technology: PIN+TIA vs. $h\nu$-detector
- high symbol rate in Gbaud range





Challenges

- coherent reception at a received power of < 1 photons/symbol
- DSP mandatory for error correction

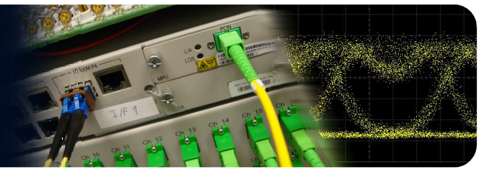
Low-Cost Coherent

EML as Coherent TRX

Coherent TDMA

“Bring quantum communication into the data centers”

Conclusions



Conclusions

Integrated EML Functions

- ✓ OTDR
- ✓ optical gate
- ✓ spectral floating
- ✓ optical neuron

EML as single-pol. Coherent TRX

- ✓ Integrated, injection-locked LO
- ✓ single fiber port } **1-to-1**
- ✓ single TRX RF port } **1-to-1**
- ✓ polarization insensitive operation through tandem-EML

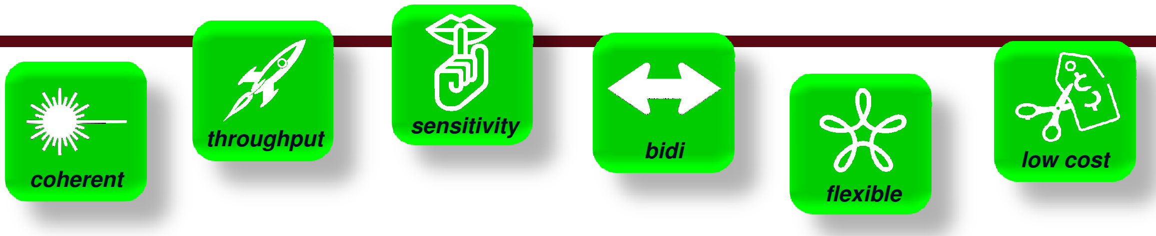
Coherent Reception in TDMA

- ✓ no DSP required: analogue coherent
- ✓ fast all-optical locking process
- ✓ correct locking to free-running transmitters in TDMA mode
- ✓ promising for short packets with low guard interval

Considerations for further work

- × substitute 50Ω front-end by **TIA**
- × advanced modulation formats

Coherent Optics Everywhere!



Acknowledgement:
This work was supported through funding from the European Research Council (ERC) under the EU Horizon 2020 R&I programme, grant agreement nº 804769 "'COYOTITO"

Bernhard Schrenk / AIT
bernhard.schrenk@ait.ac.at