Continuous-Variable Quantum Key Distribution at 10 GBaud using an Integrated Photonic-Electronic Receiver

Adnan A.E. Hajomer [1,*], Cédric Bruynsteen [2], Ivan Derkach [1,3], Nitin Jain [1], Axl Bomhals [2], Sarah Bastiaens [2], Ulrik Lund Andersen [1], Xin Yin [2], And

Tobias Gehring [1]

E-mail : aaeha@dtu.dk

[1] Department of Physics, Technical University of Denmark, 2800 Lyngby, Denmark.

[2] Ghent University-imec, IDLab, Dep. INTEC, 9052 Ghent, Belgium

[3] Department of Optics, Faculty of Science, Palacky University, Czech Republic

Danmarks Grundforskningsfond Danish National Research Foundation

Innovation Fund Denmark

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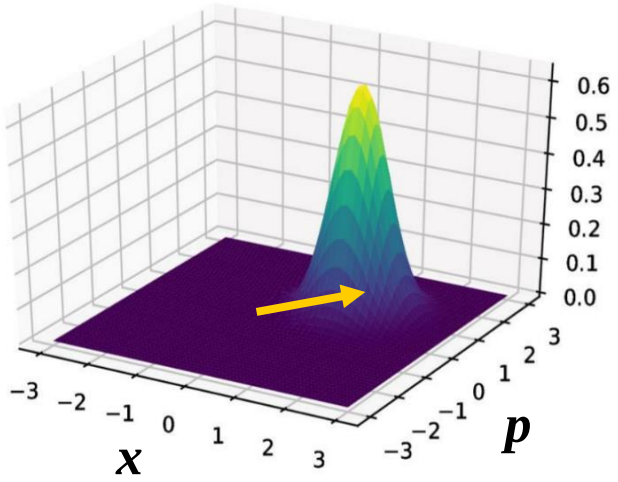
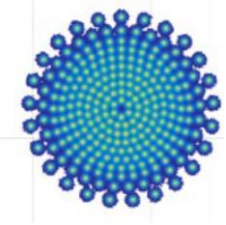
Introduction to CVQKD

Information is encoded in continuous degrees of freedom of light, such as amplitude and phase (x and p) quadratures.

Alice prepares coherent states





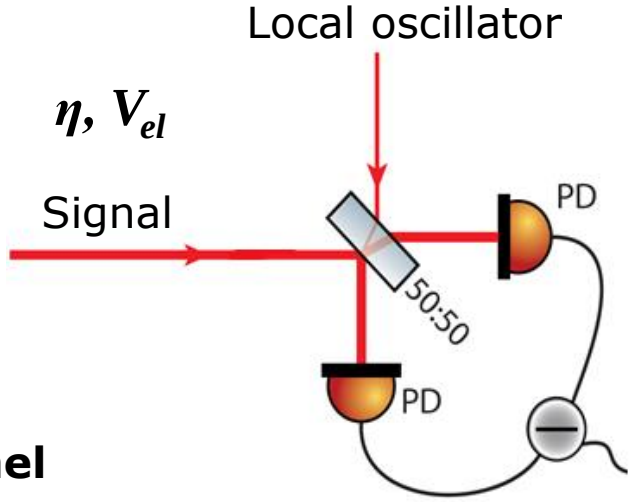
V_M

Eve

Quantum channel

T, ξ

Bob measures by coherent detection



V_B

Public authenticated channel

$$V_B = 1 + \eta T V_M/2 + V_{\mathrm{el}} + \xi_B$$

Homodyne or heterodyne

Classical processing: Parameter estimation, error correction and privacy amplification

S. Pirandola *et al.*, Advances in optics and Photonics 12, 4(2020)

Why CVQKD?

- Homodyne/heterodyne detection for decoding.
  Standard telecom components work at room temperature.

- High rates.

S. Pirandola *et al*., *Nature communications* 8,1 (2017)

F. Laudenbach, *et al. Advanced Quantum Technologies* 1, 1 (2018): 1800011.

CVQKD: Asymptotic key rate

Efficiency

Mutual information

Frame error rate

Holevo information

$$\text{Key rate (bits/s)} = \mathrm{R}_{\text{symbol}}(1 - FER)(\beta I_{AB} - \chi_{EB}(\xi, T))$$

Symbol rate, symbol/s

Secret key fraction (SKF), bits/symbol

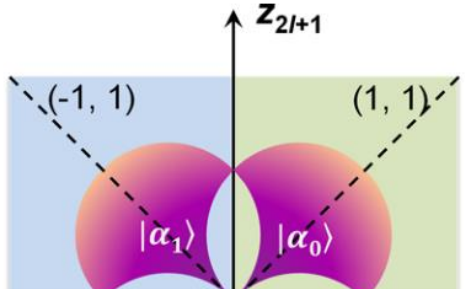
F. Laudenbach, *et al*. *Advanced Quantum Technologies* 1.1 (2018): 1800011.

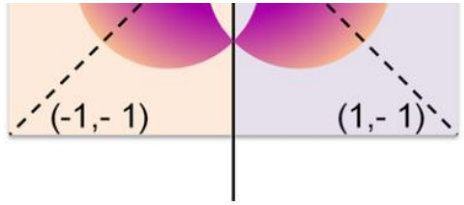
Roadmap of High-rate CVQKD

Publication	Modulation	Symbol rate (Mbaud)
2021-H.-M. Chin	Gaussian	20
2015-C. Wang	Gaussian	25
2018-T. Wang	Gaussian	50
2015-D. Huang	Gaussian	50
2022-J.Nitin	Gaussian	100

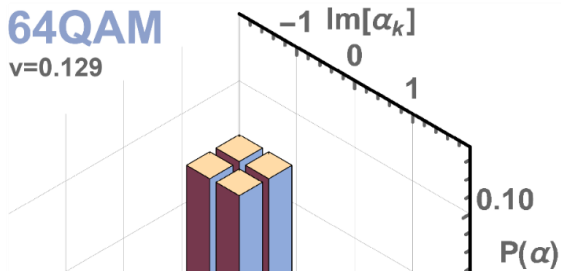
- Mature security proof and best performance
- DAC/ADC with high bits resolution is required

Discrete Modulation CVQKD

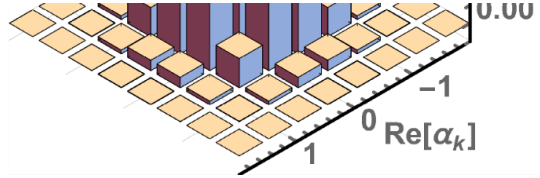




Quadrature Phase Shift Keying (QPSK)



Bandwidth limitation

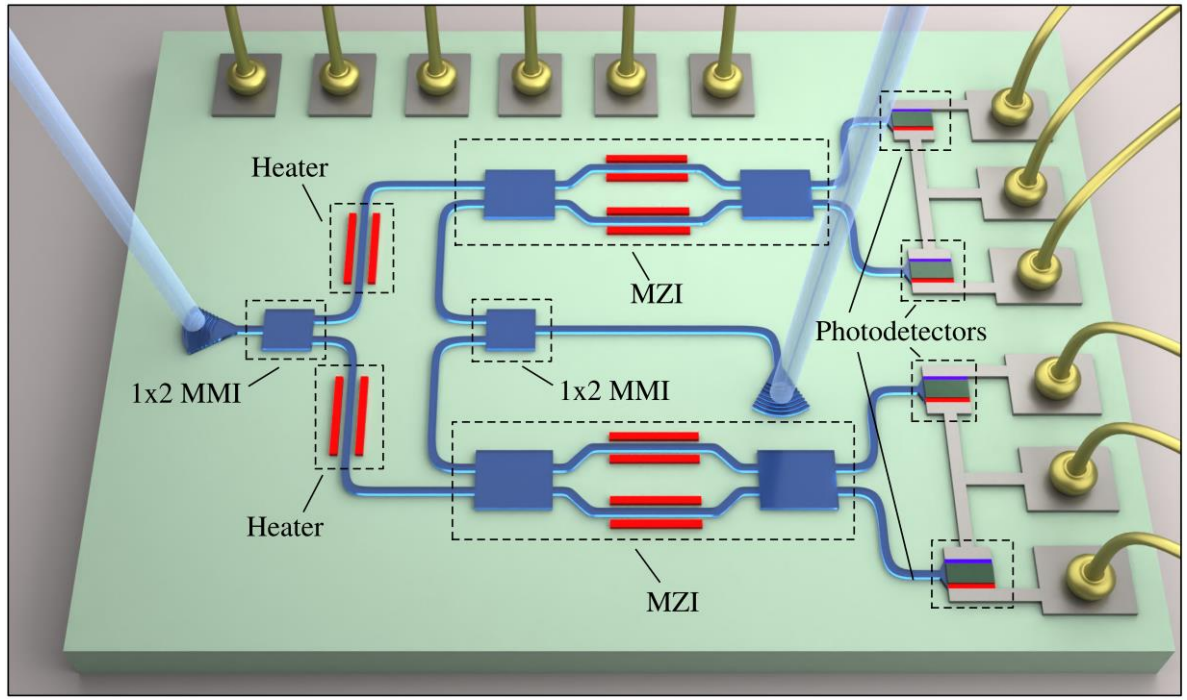


Probabilistic Constellation Shaping quadrature amplitude modulation (PCS QAM)

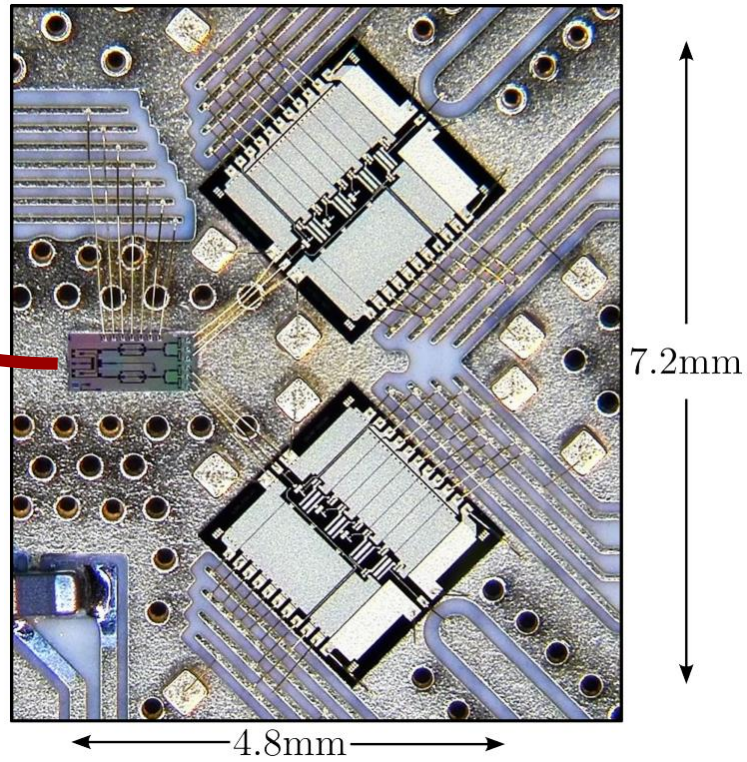
Publication	Modulation	Symbol rate (Gbaud)
2022 - H. Wang	QPSK	5
2022 - F. Roumestan	PCS QAM	0.6
2022 - Y. Pan	PCS QAM	1

A. Denys, *et al. Quantum 5, 540 (2021).* S. Ghorai *et al. Phys,Rev. X, (2021).*

Integrated Photonic-Electronic Receiver



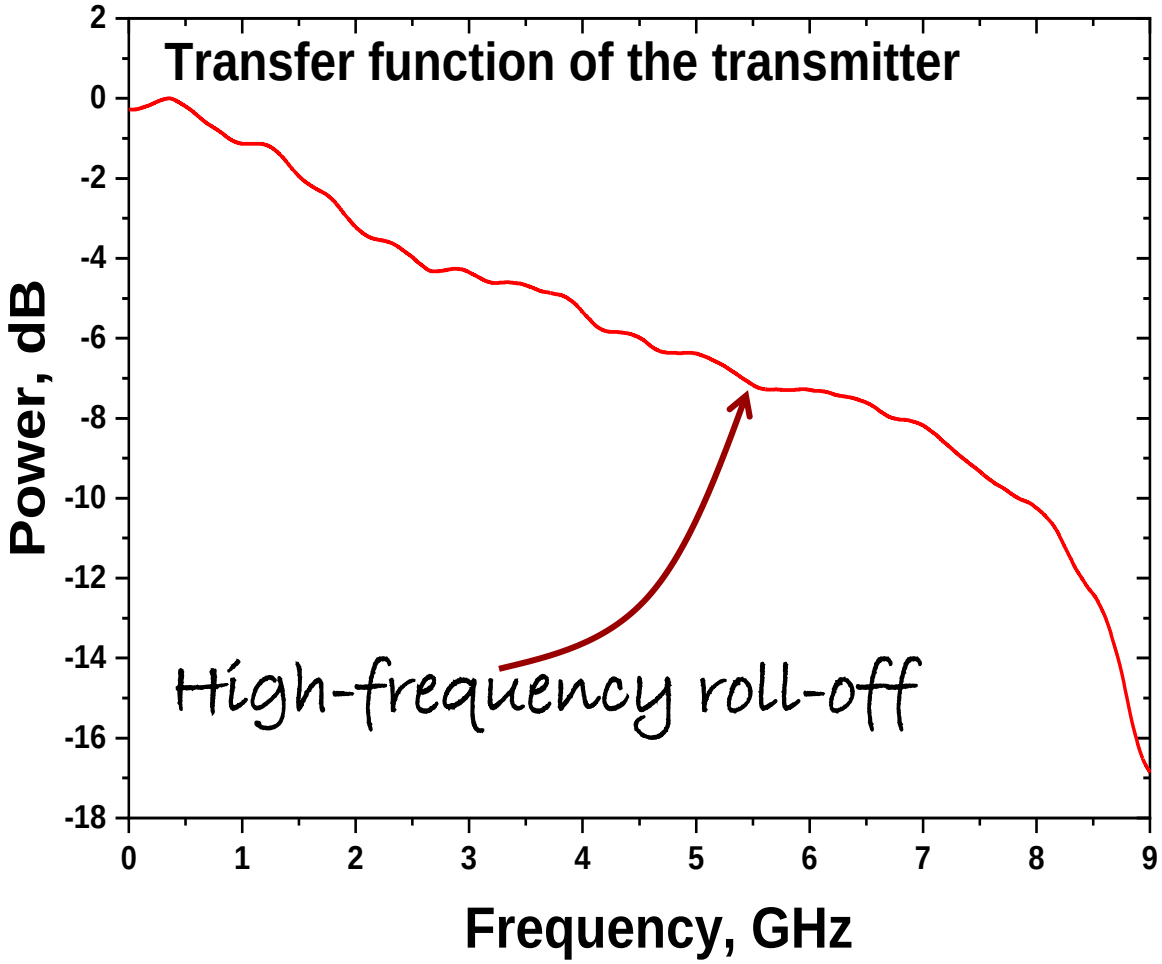
Photonic IC



Micrograph assembly

Platform	Bandwidth	Insertion loss	Total efficiency	Transimpedance amplifier
Imec's iSiPP50G	20 GHz	2.5 dB	44 %	100nm GaAs pHEMT

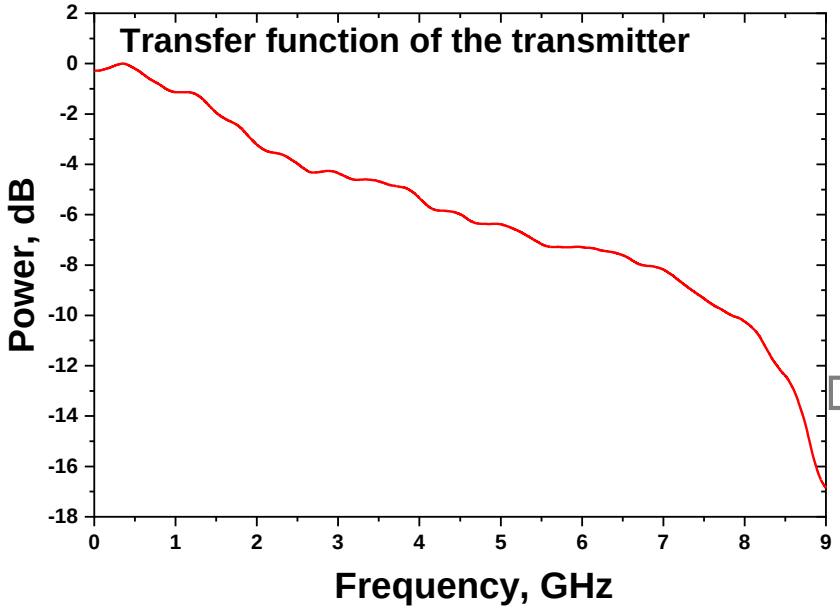
High-frequency roll-off of the transmitter



- Independent and Identically Distributed (I.I.D) symbols
- High excess noise

A.A.E. Hajomer, *et al. npj Quantum Information* 8.1 (2022)

Digital signal processing (DSP) for state preparation



Random numbers

PCS

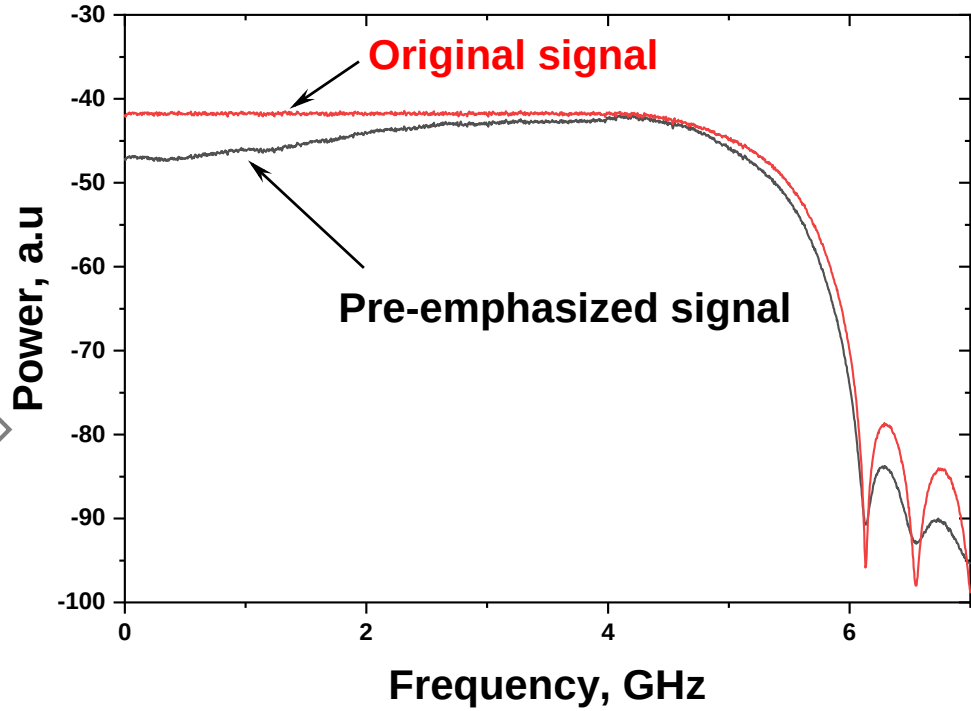
Upsampling

Pulse shaping

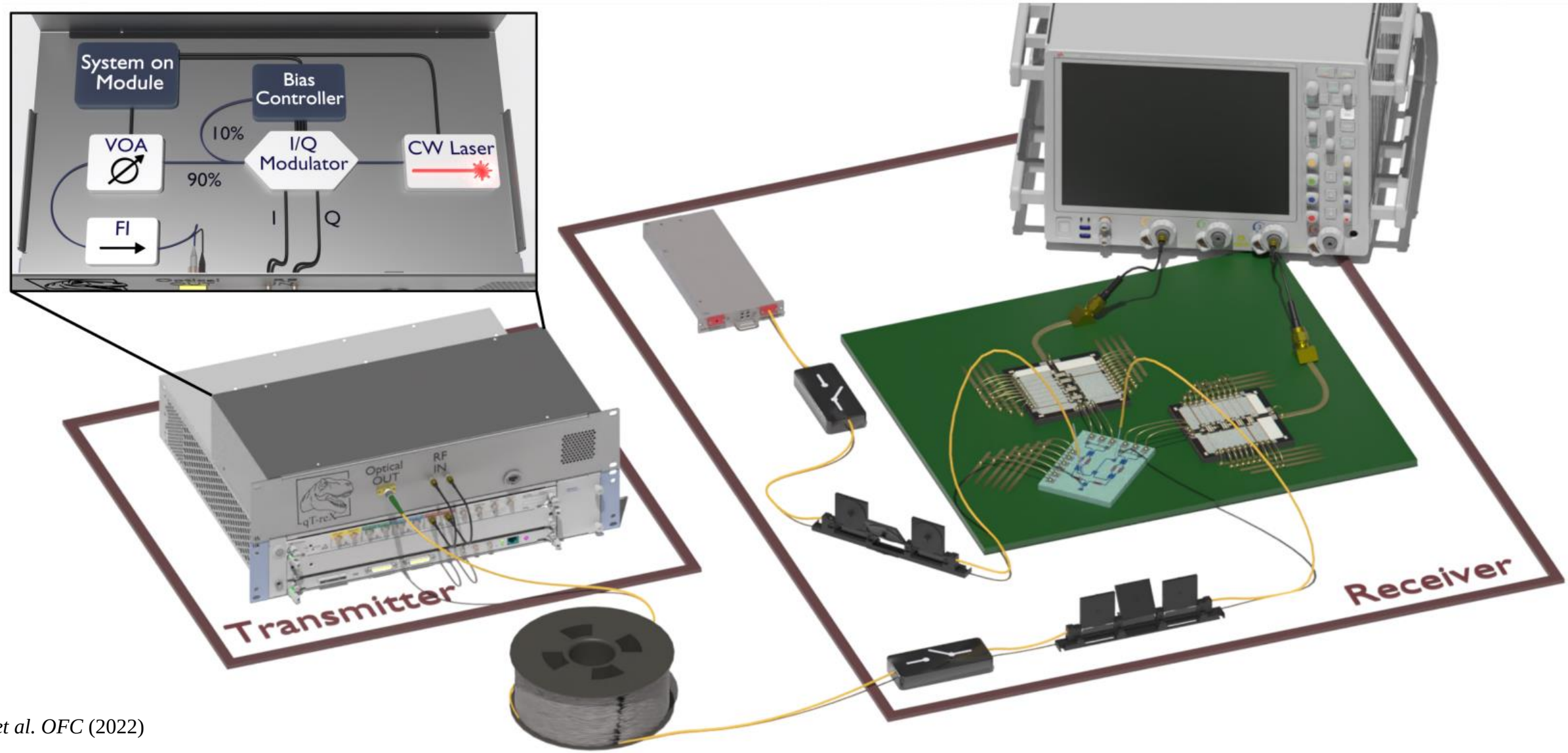
Pre-emphasis

Pilot addition

Arbitrary waveform generator (AWG)



Gbaud CVQKD System

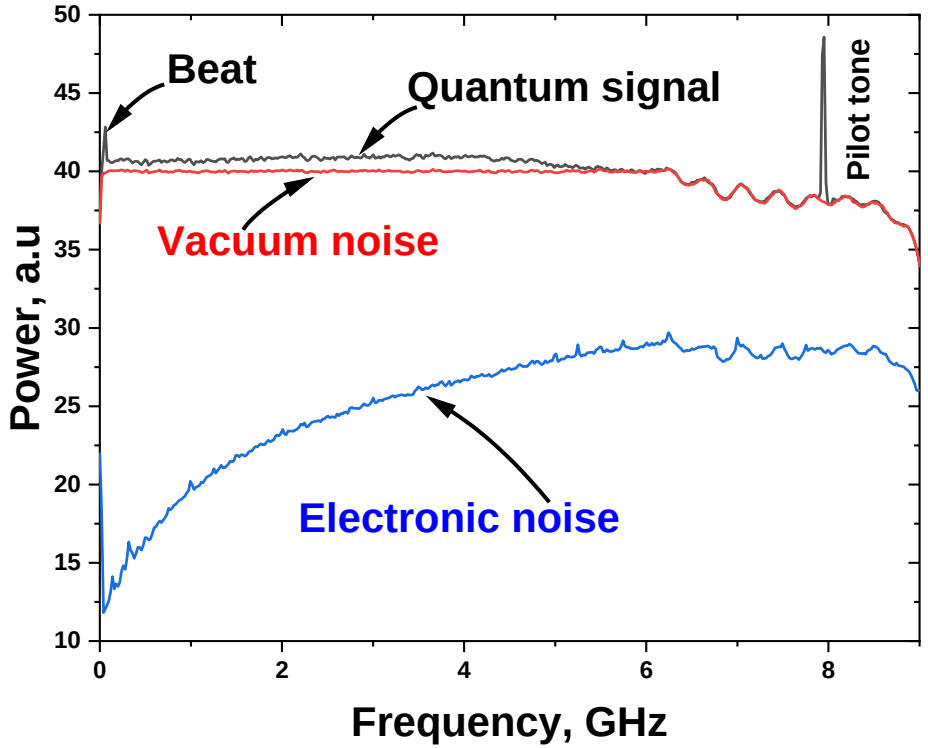


N. Jain, *et al. OFC* (2022)

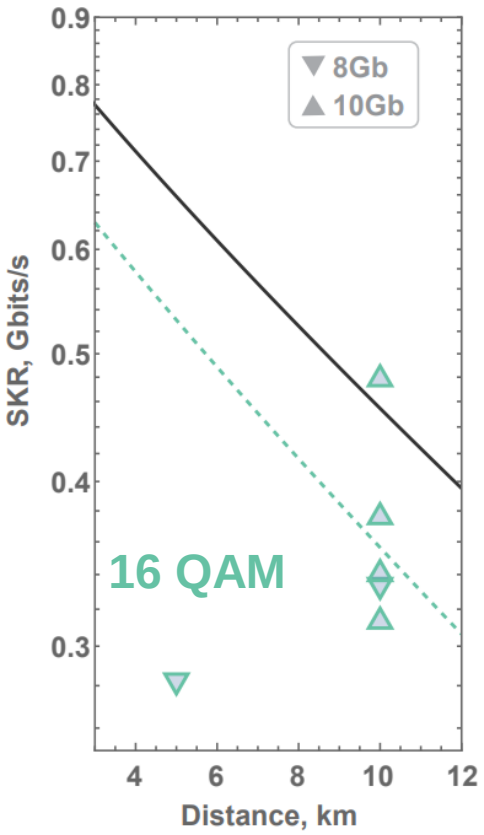
Receiver : DSP for quantum symbol recovery

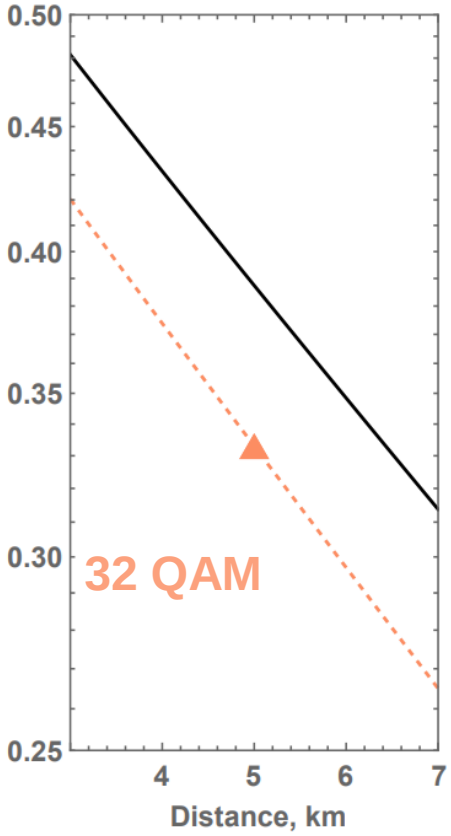
Real-time oscilloscope

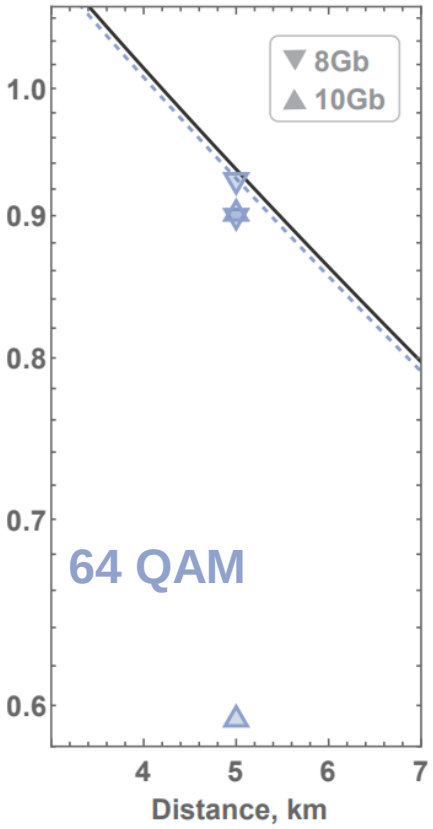
- Whitening filter
- Frequency and phase estimation
- Time synchronization
- Matched filtering
- Downsampling

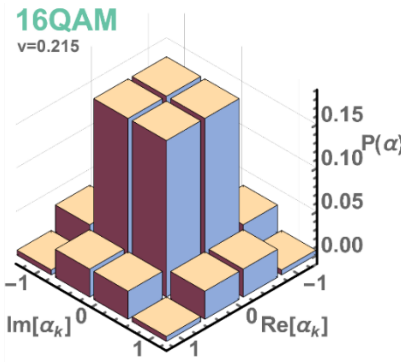


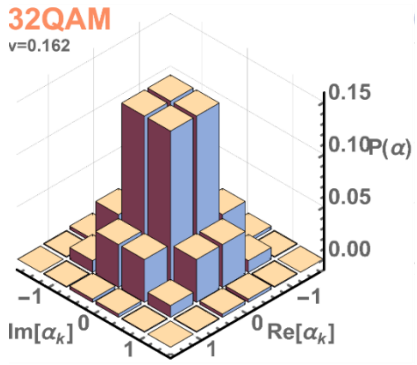
Results

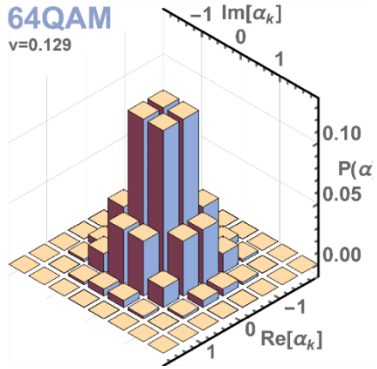












Symbol rate, GBaud	Distance, km	V_M, SNU	T	Excess noise, % SNU
8	10	1.02	0.684	3.4085
10	5	0.90	0.569	4.9025

Summary

- We reported a record experiment of a 10 Gbaud CVQKD system.
- This is achieved by :
  - Broadband Integrated Photonic-Electronic Receiver.
  - Well-engineered DSP for quantum state preparation and measurement.

The Team


A. Hajomer


N. Jain


I. Derkach


U. L. Andersen

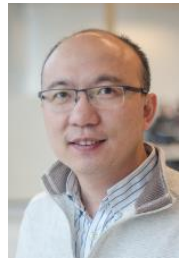

T. Gehring

DTU Physics


C. Bruynsteen


A. Bomhals


S. Bastiaens


X. Yin

Ghent University-imec