A Fast QKD Prototype Based on Photonic Integrated Circuits

Maria Ana de Matos Afonso Pereira

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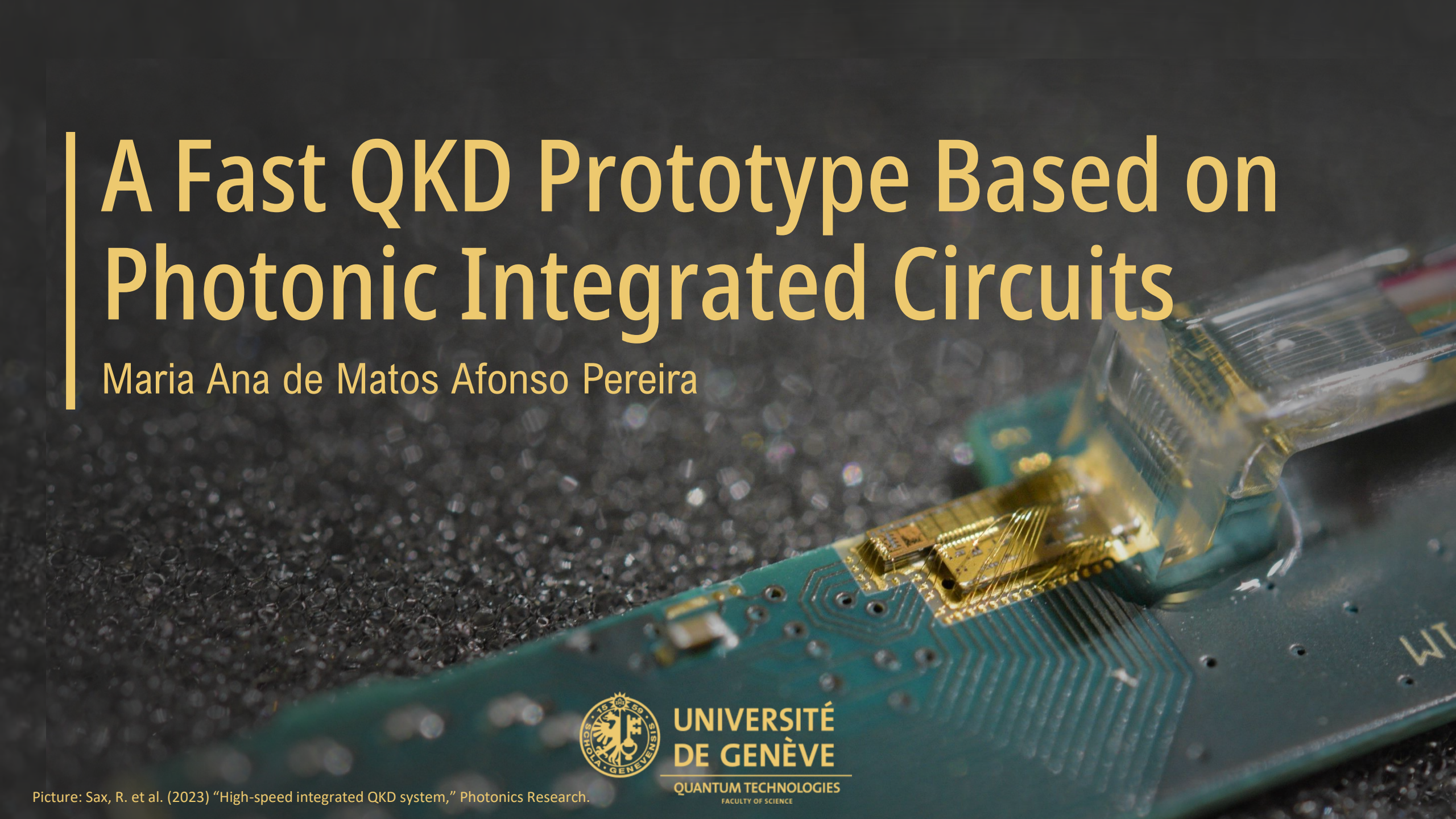

Picture: Sax, R. et al. (2023) “High-speed integrated QKD system,” Photonics Research.

Motivation

QKD (Quantum Key Distribution)

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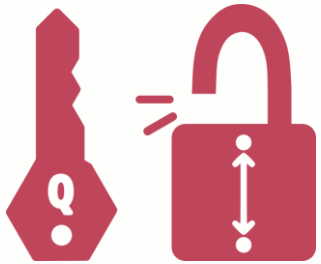
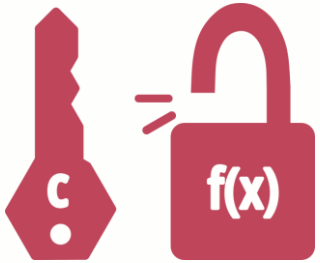


Quantum Cryptography



Classical Cryptography

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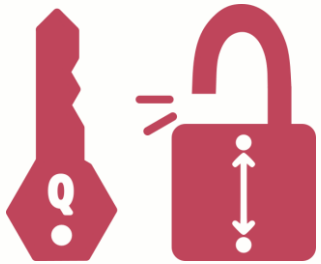
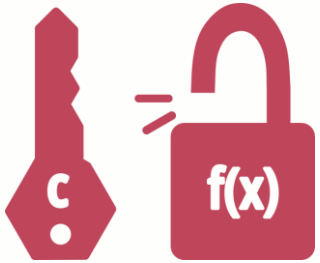


Quantum Cryptography

- based on the laws of **quantum mechanics**



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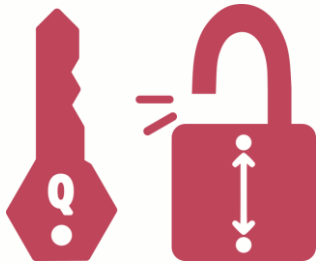
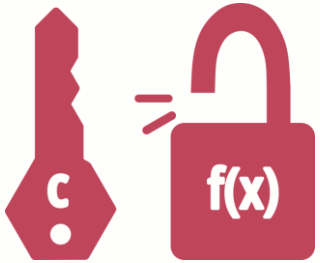


Quantum Cryptography

- based on the laws of **quantum mechanics**

→ **information theoretically secure**



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→ **security based on assumptions** on the technological limitations of eavesdroppers

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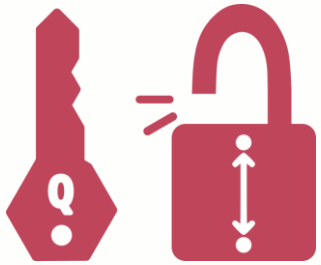

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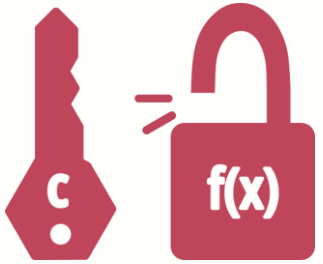

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long term private communications

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Motivation

QKD has been maturing over the past 4 decades

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Recent interest of companies and governments in QKD for **network applications**.

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↓

Recent interest of companies and governments in QKD for **network applications**.

↓

Integrated transmitters and **receivers:**

Practical Compact Scalable

Motivation

Goal: Development of a **small**, **portable** and **ready-to-use high-speed QKD** platform based on Photonic Integrated Circuits (**PIC**).

The protocol

Time Encoded 3-State BB84 with 1 Decoy

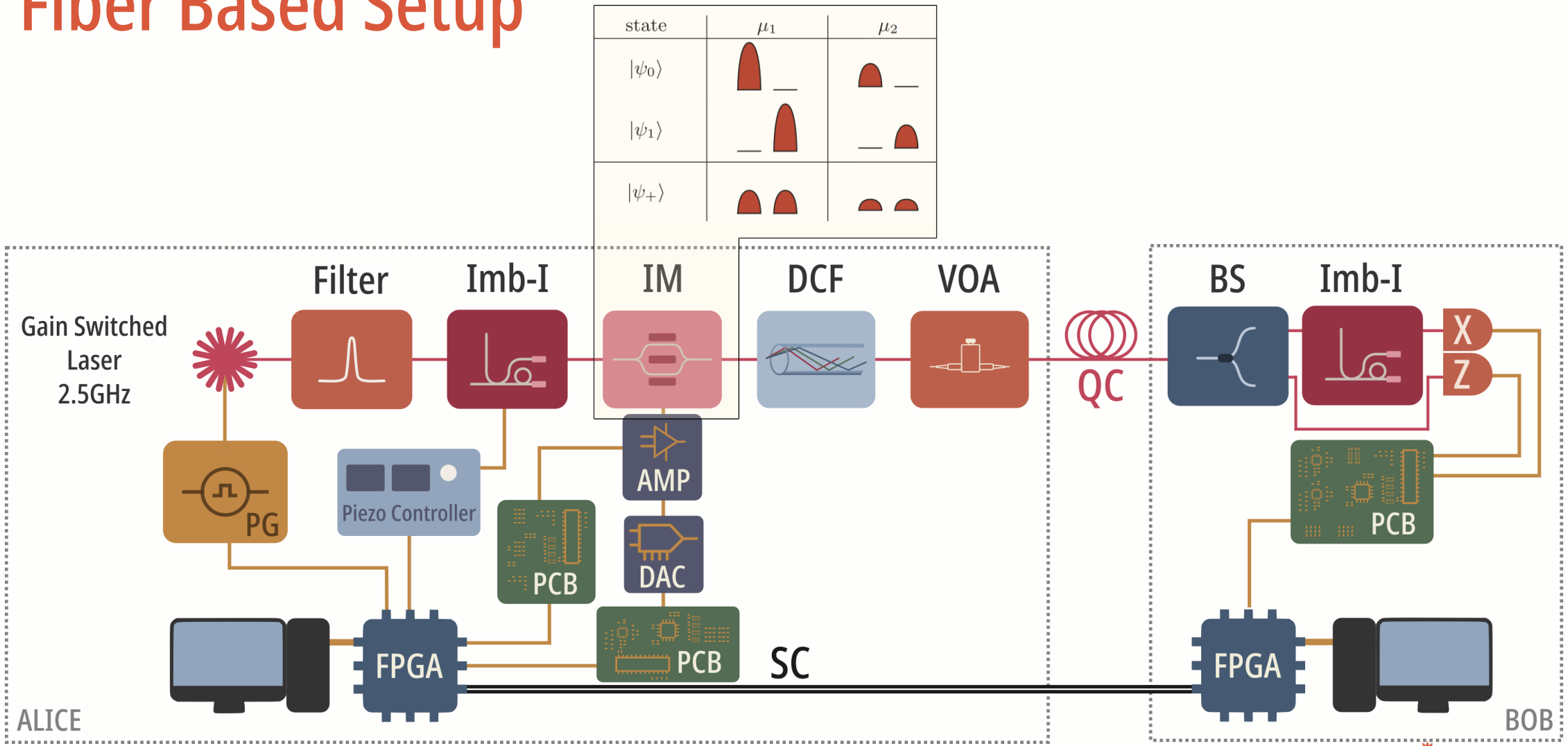
The protocol

Time Encoded 3-State BB84 with 1 Decoy

Base	bit	State	μ_1	μ_2
Z raw key	0	$\|\varphi_0\rangle = \|\alpha\rangle_E + \|0\rangle_L$		
	1	$\|\varphi_1\rangle = \|0\rangle_E + \|\alpha\rangle_L$		
X estimate security		$\|\varphi_+\rangle = \frac{1}{\sqrt{2}}(\|\varphi_1\rangle + \|\varphi_0\rangle)$		

Adapted from: Boaron, A. *et al.* (2018) *Applied Physics Letters*, 112(17), p. 171108. https://doi.org/10.1063/1.5027030.

Fiber Based Setup



I-MZI → Imbalanced Mach Zehnder Interferometer; **IM**→ Intensity Modulator; **DCF**→ Dispertion Compensanting Fiber; **VOA**→ Variable Optical Attenuator; **BS**→ Beam Splitter; **PCB**→ Printed Circuit Board; **PG**→ Pulse Generator.

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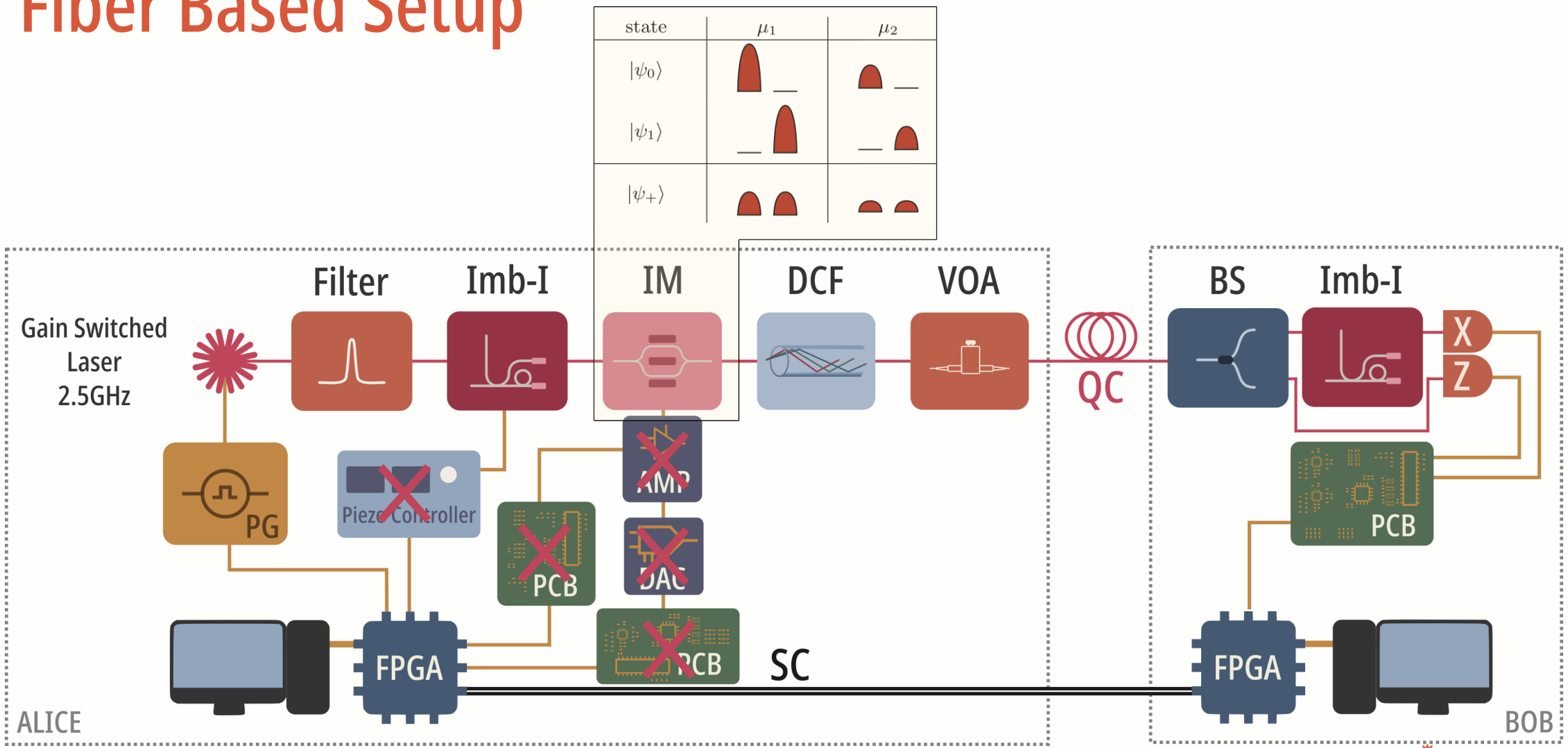

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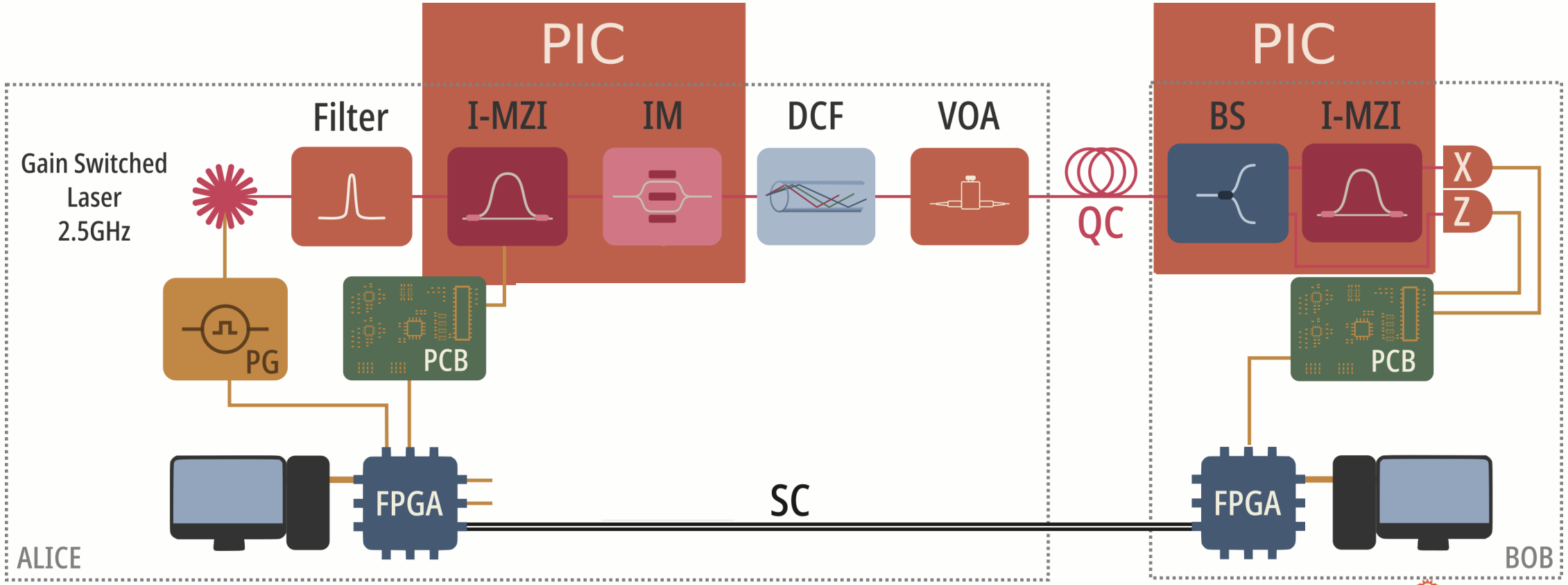

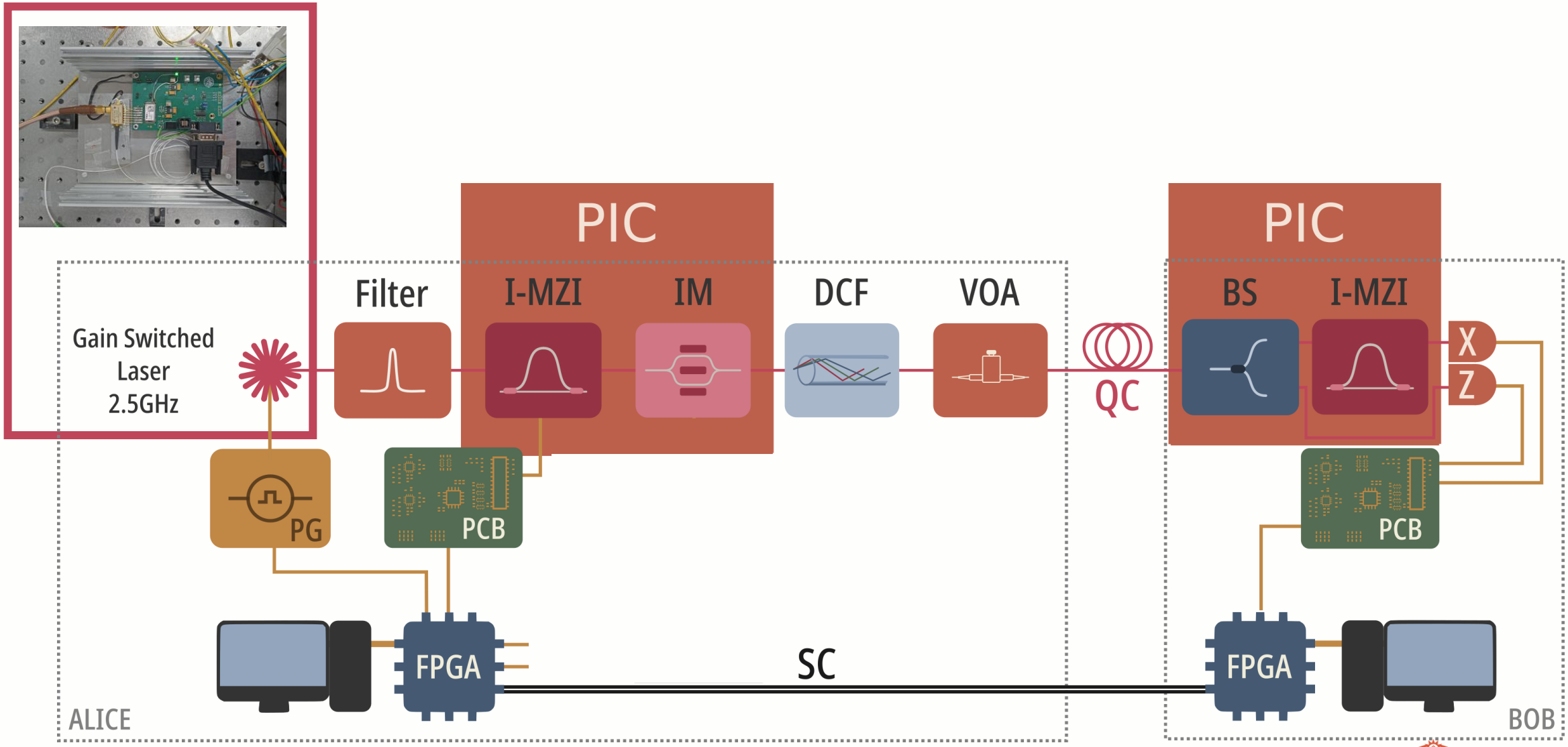

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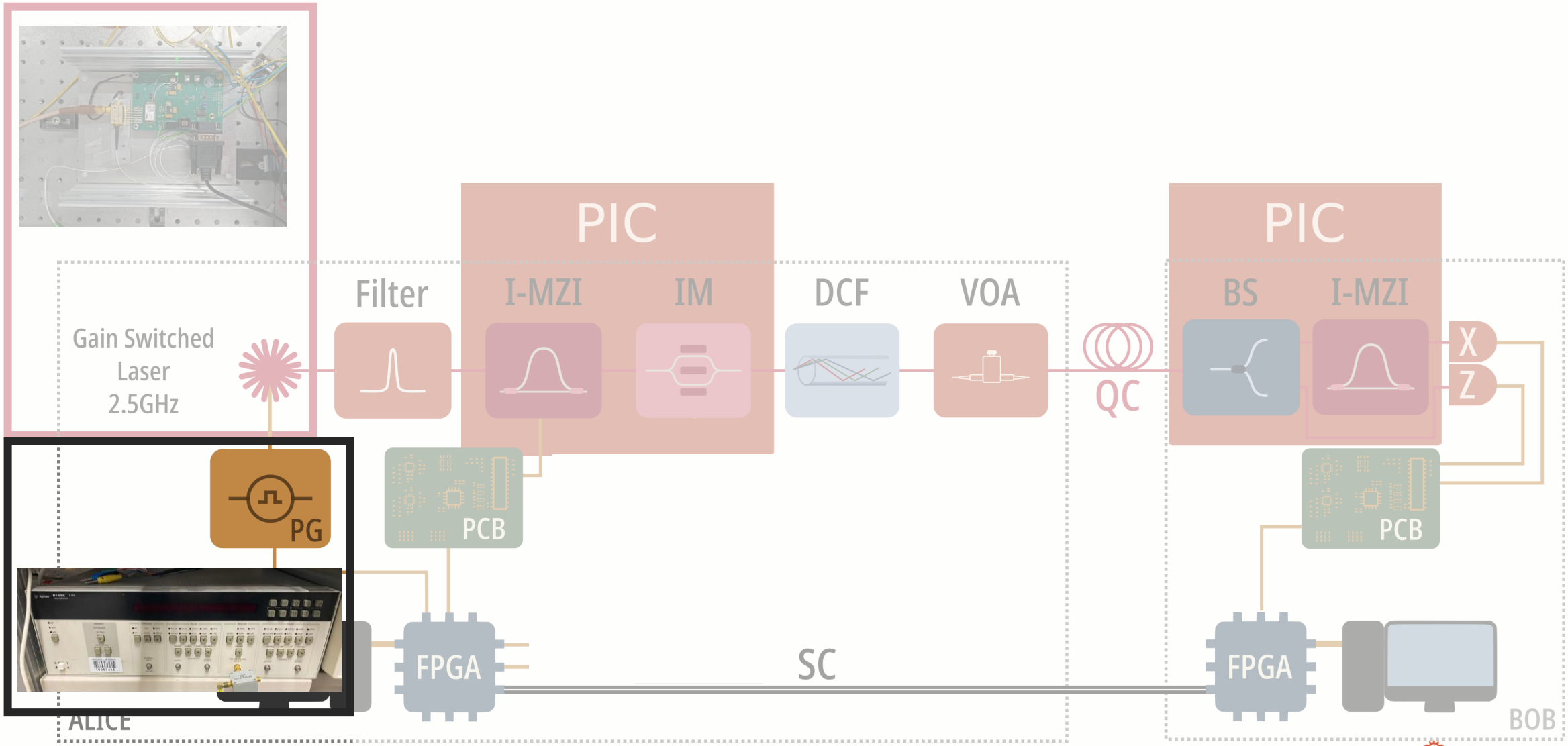

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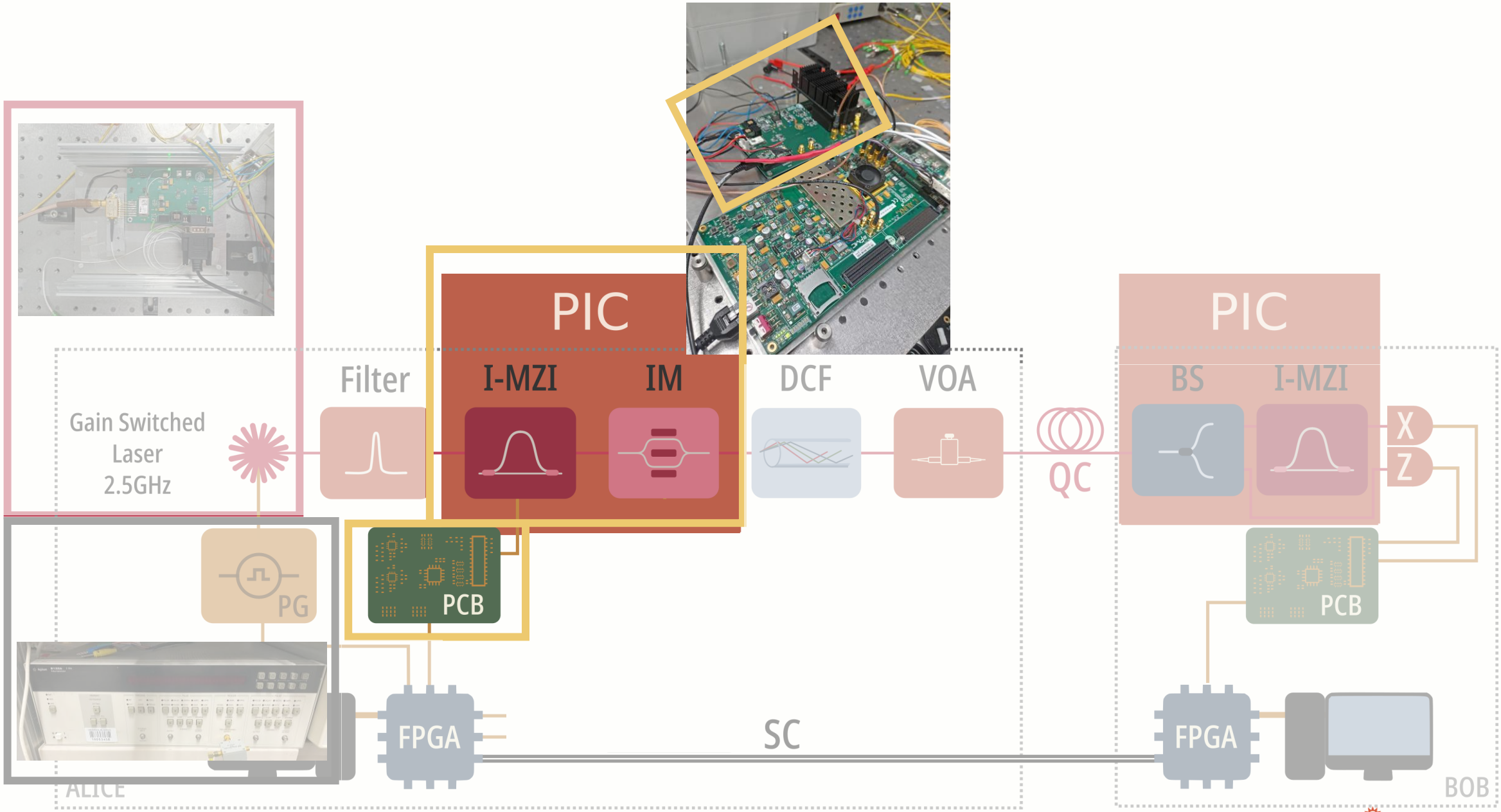

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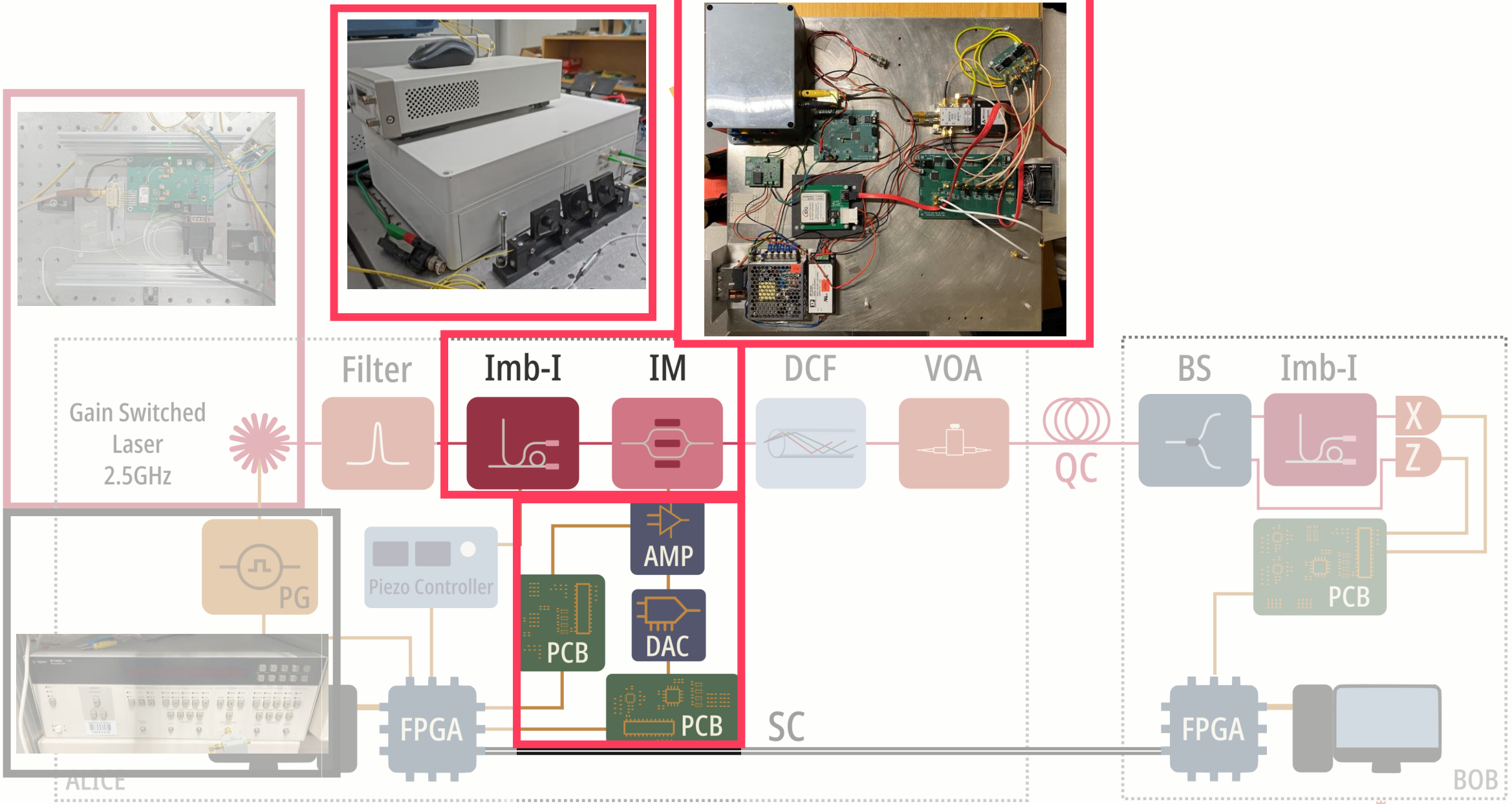

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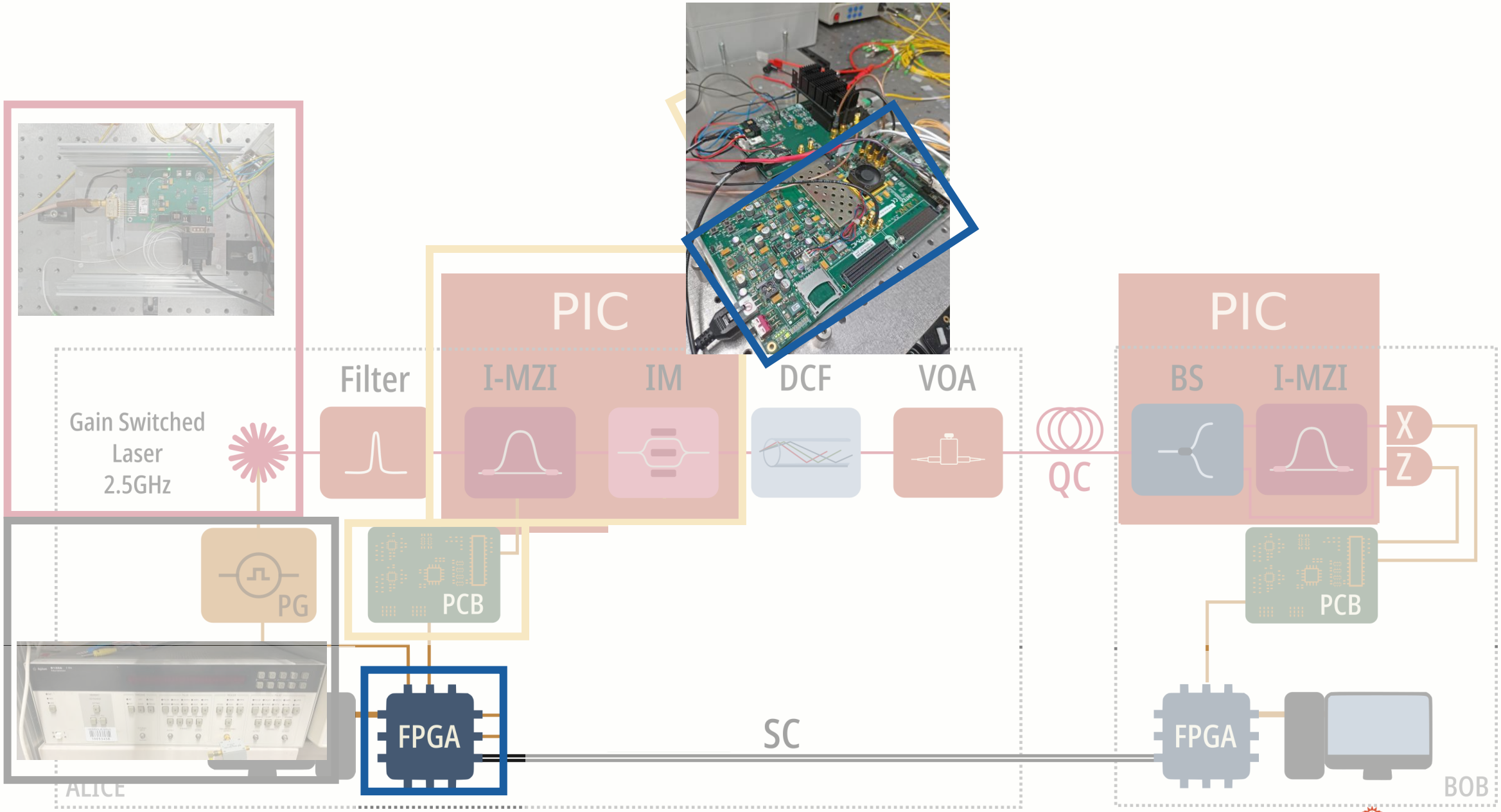

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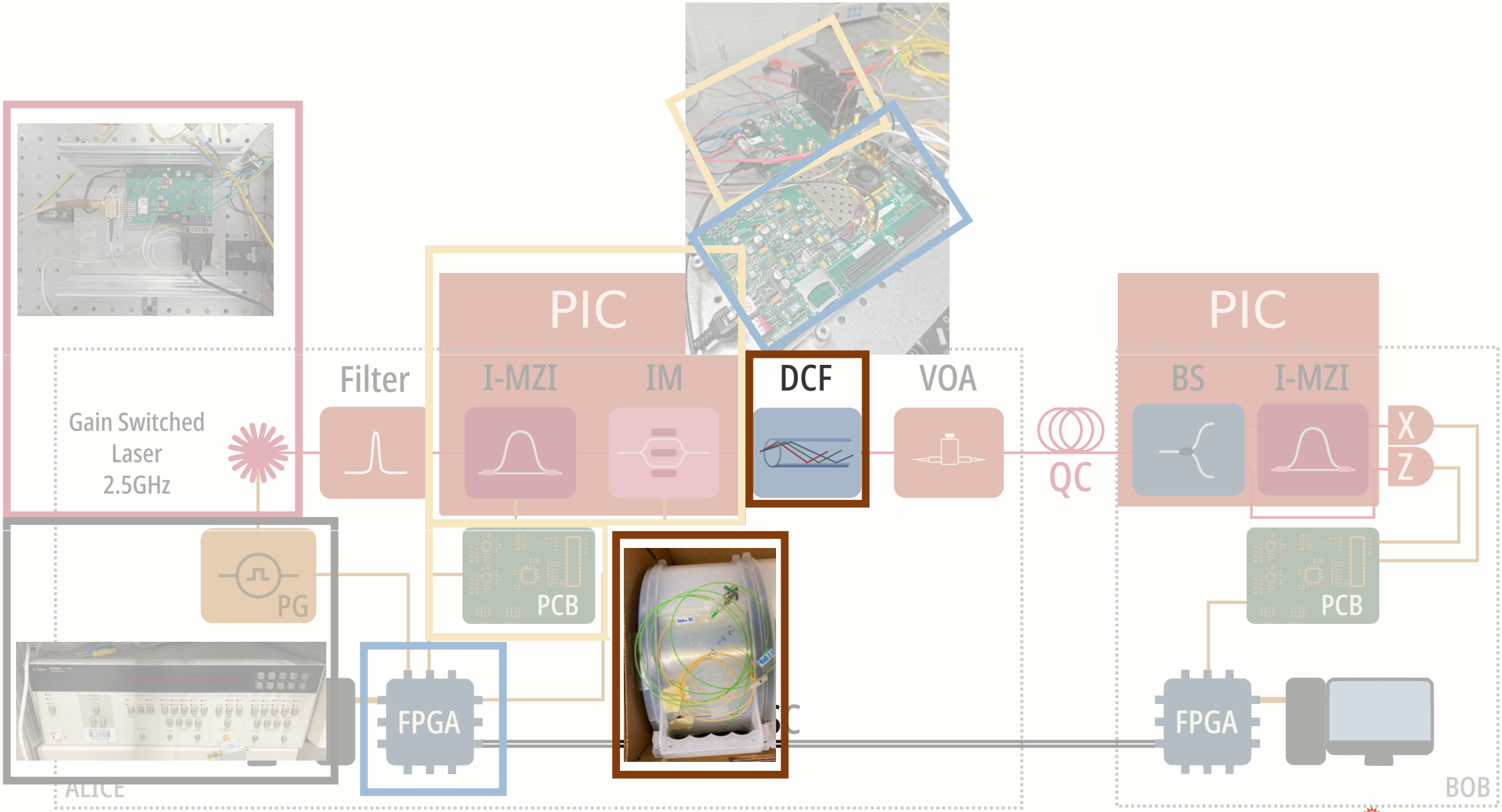

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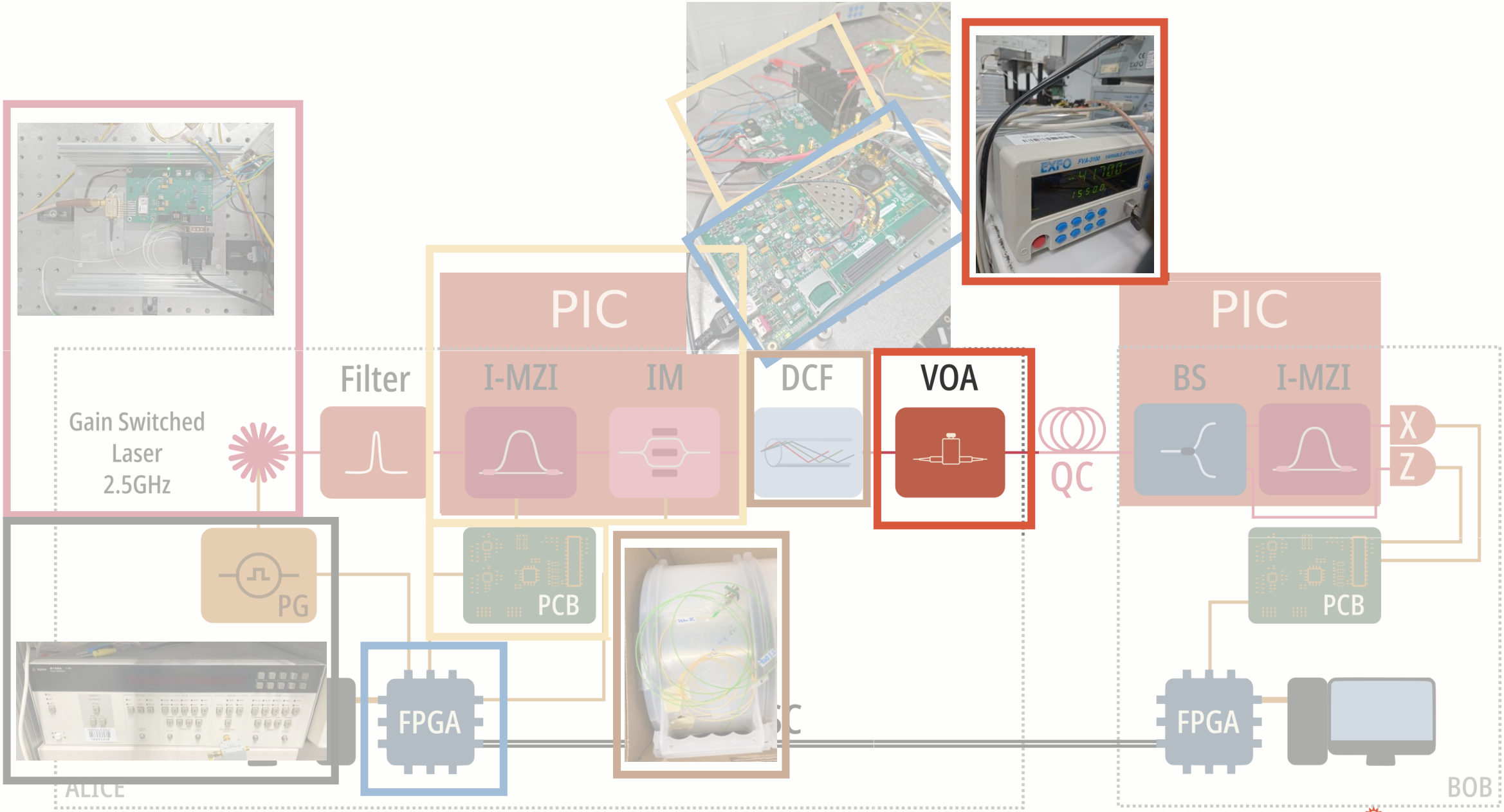

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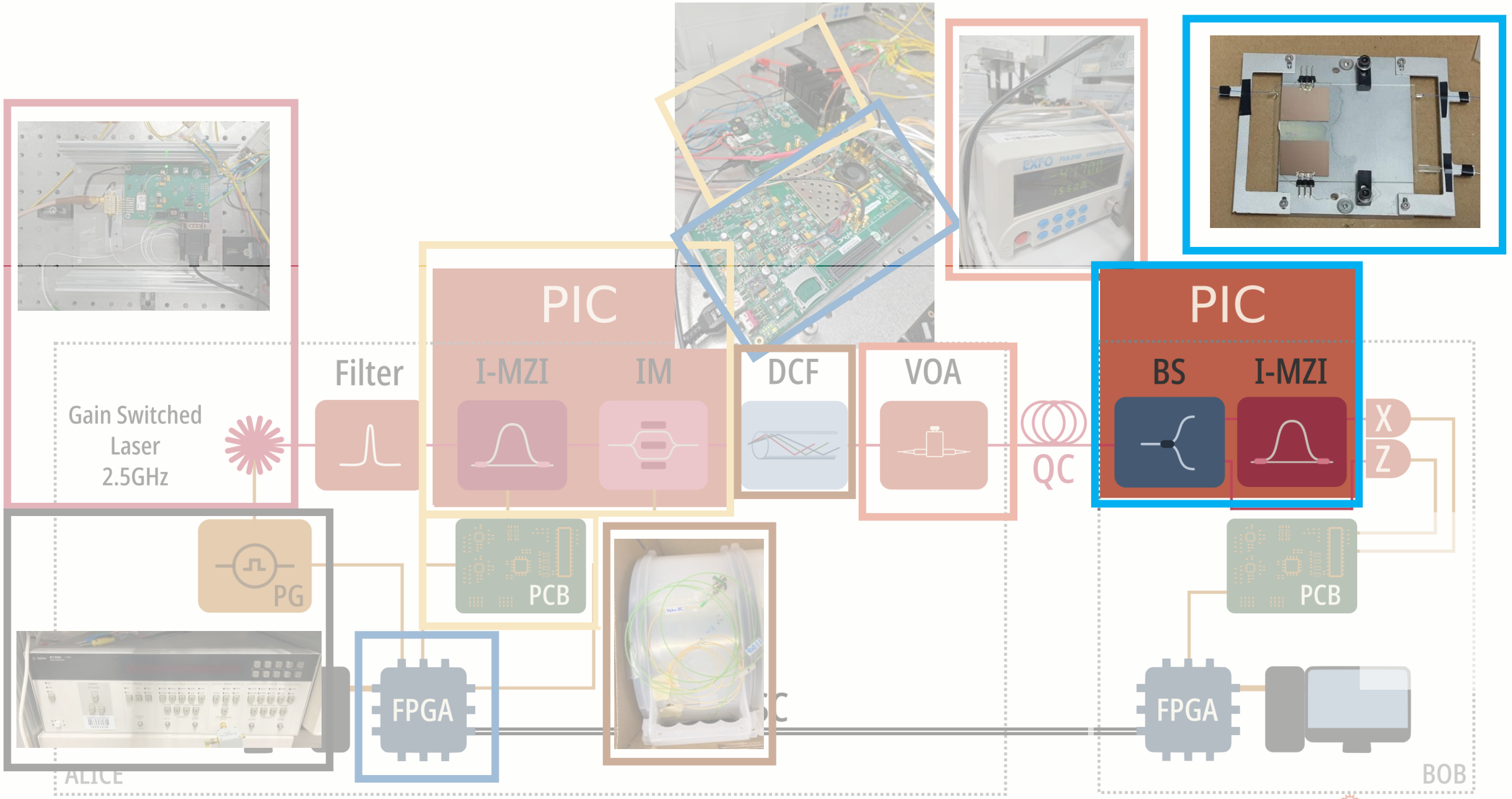

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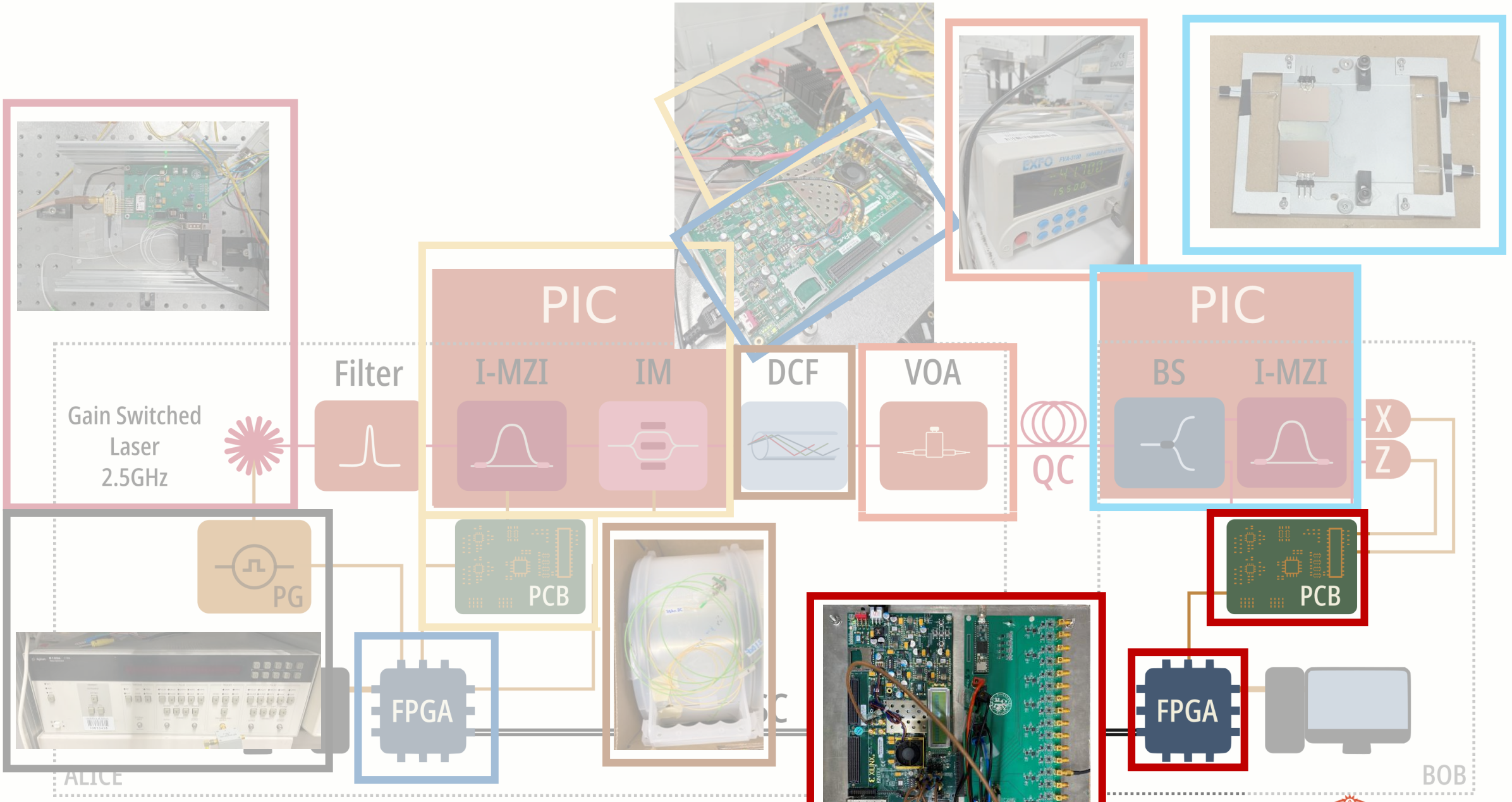

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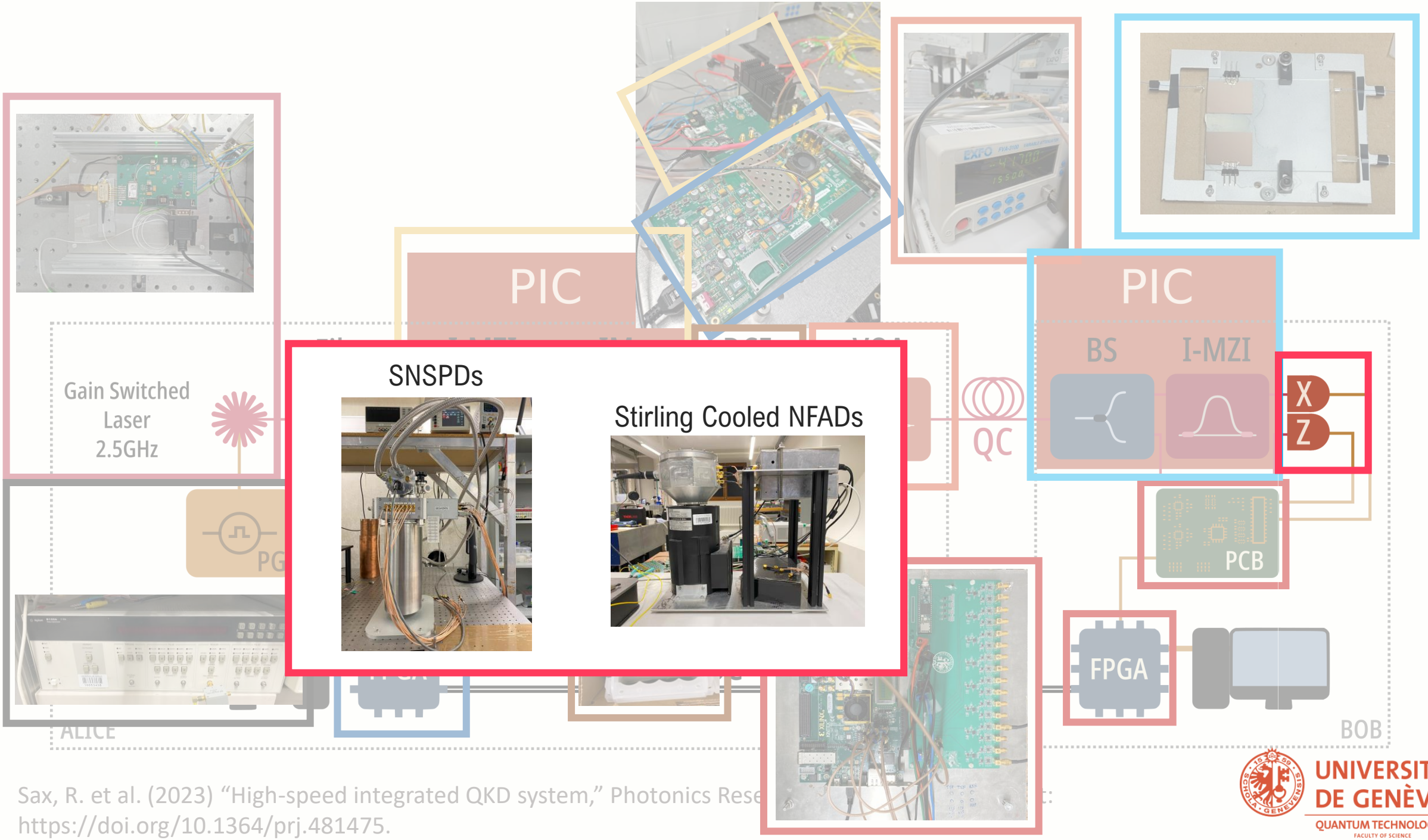

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This Work

MAIN CHANGES:

- **Peltier** cooled NFADS (Negative Feedback Avalanche Diodes);

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Why?

- Higher Quality State Preparation;
- Less dependent on detector's jitter;
- Less sensitive to chromatic fiber dispersion.

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Lower QBER

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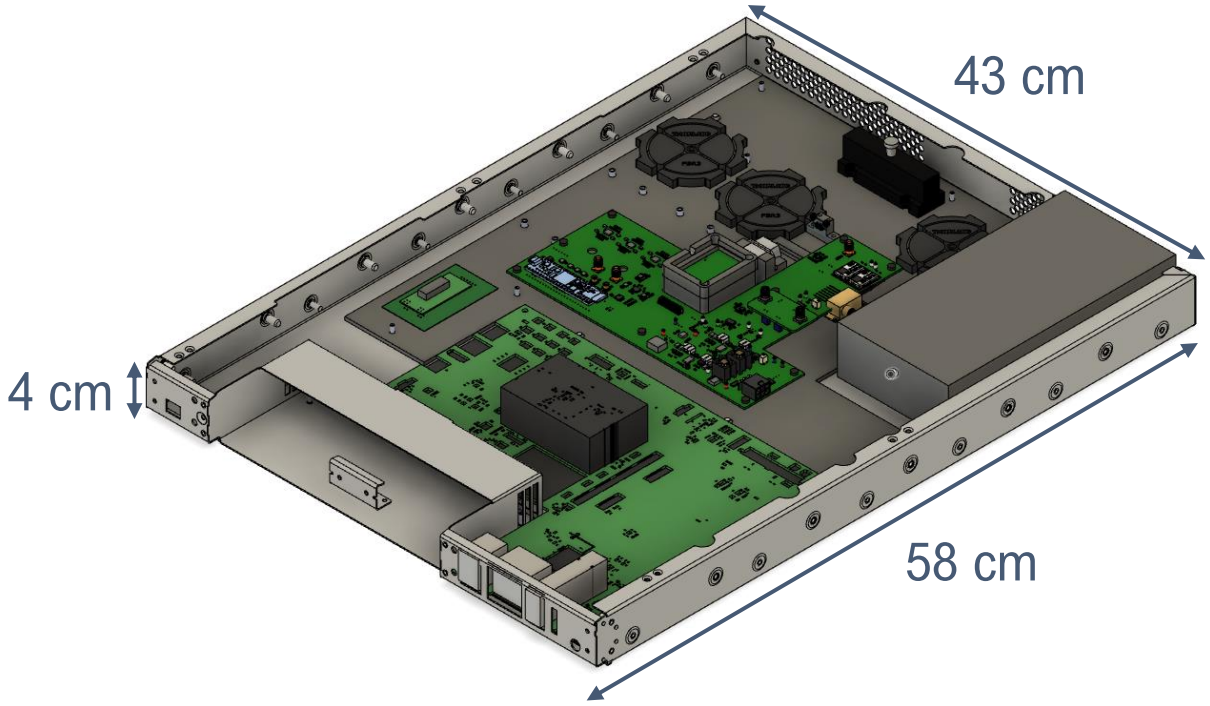
- Added **pulse generation, LASER driving** and **temperature control** to **one PCB**.
- **Small-scale VOA** inside transmitter's unit.
- **Scaled down PCs**.

Setup

ALICE



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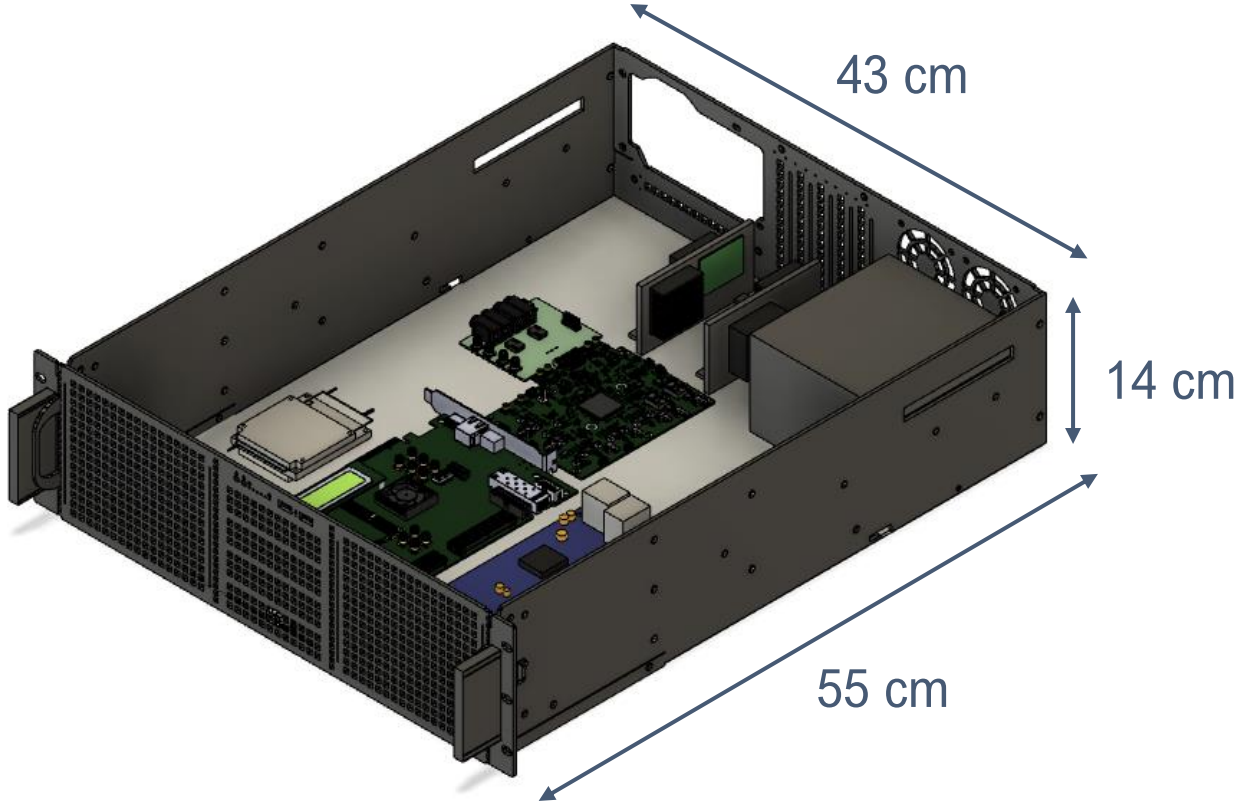

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Setup

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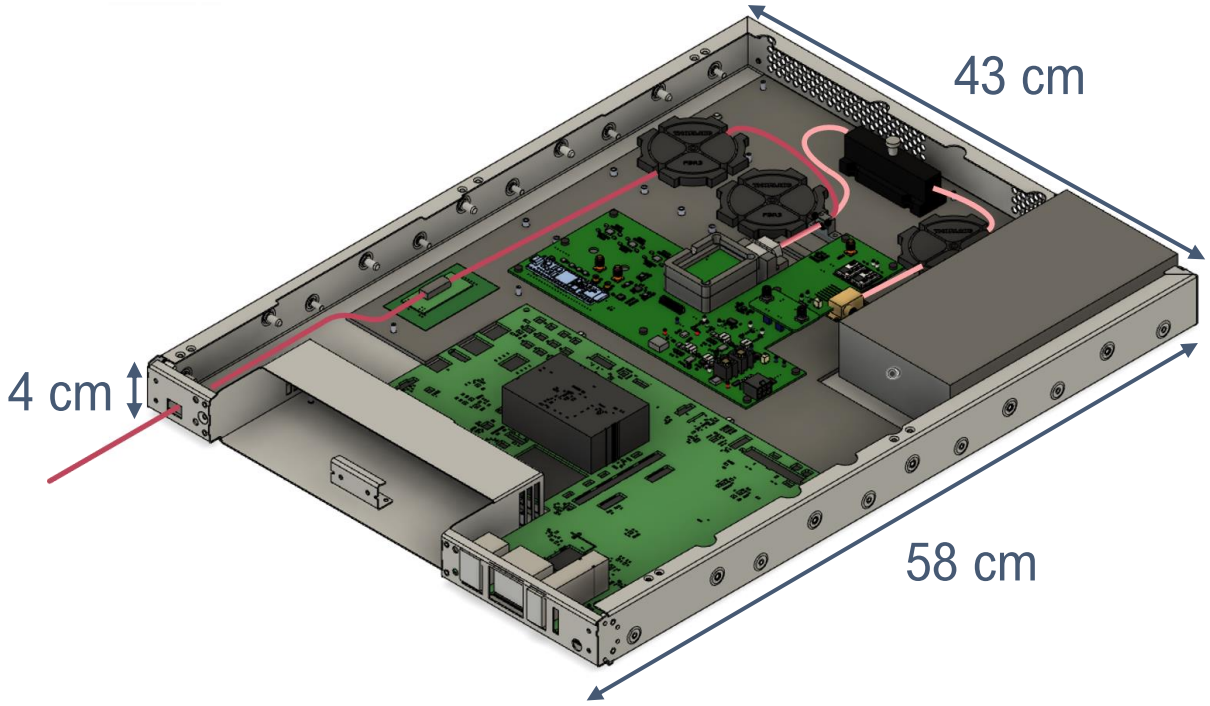

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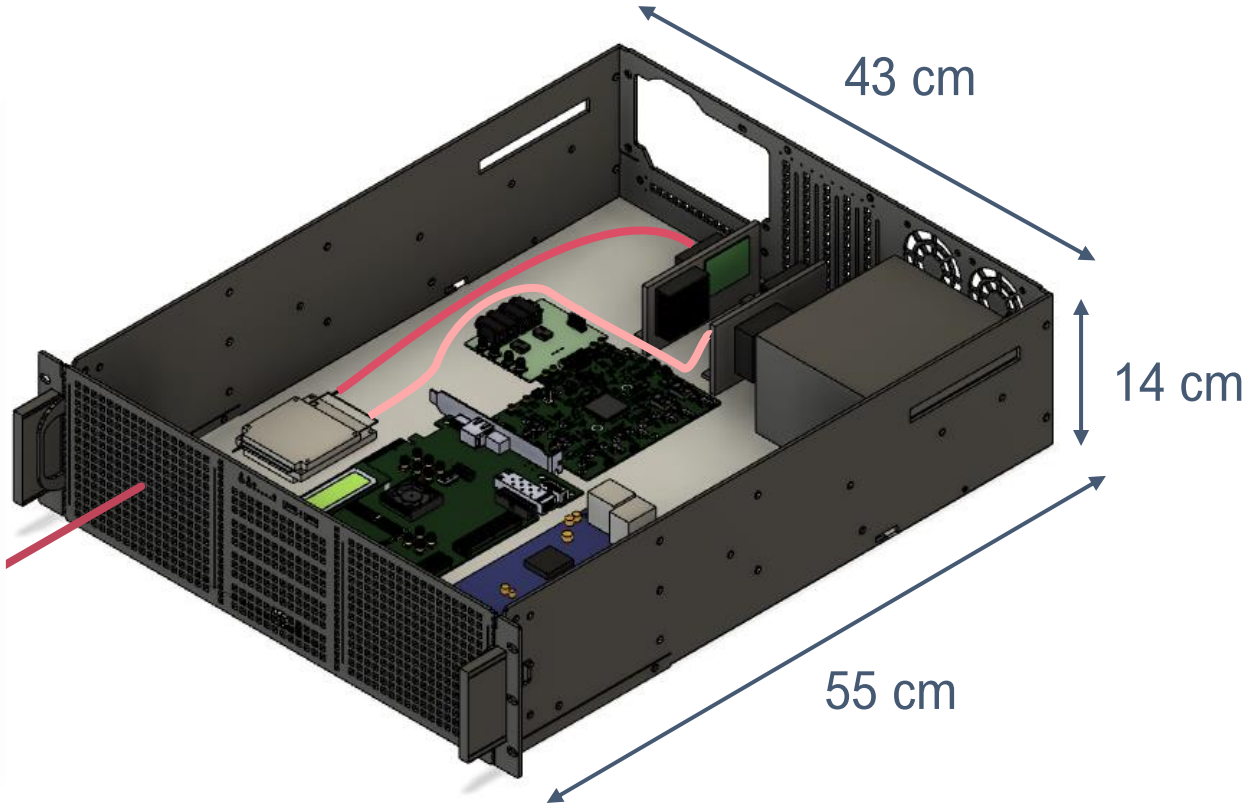

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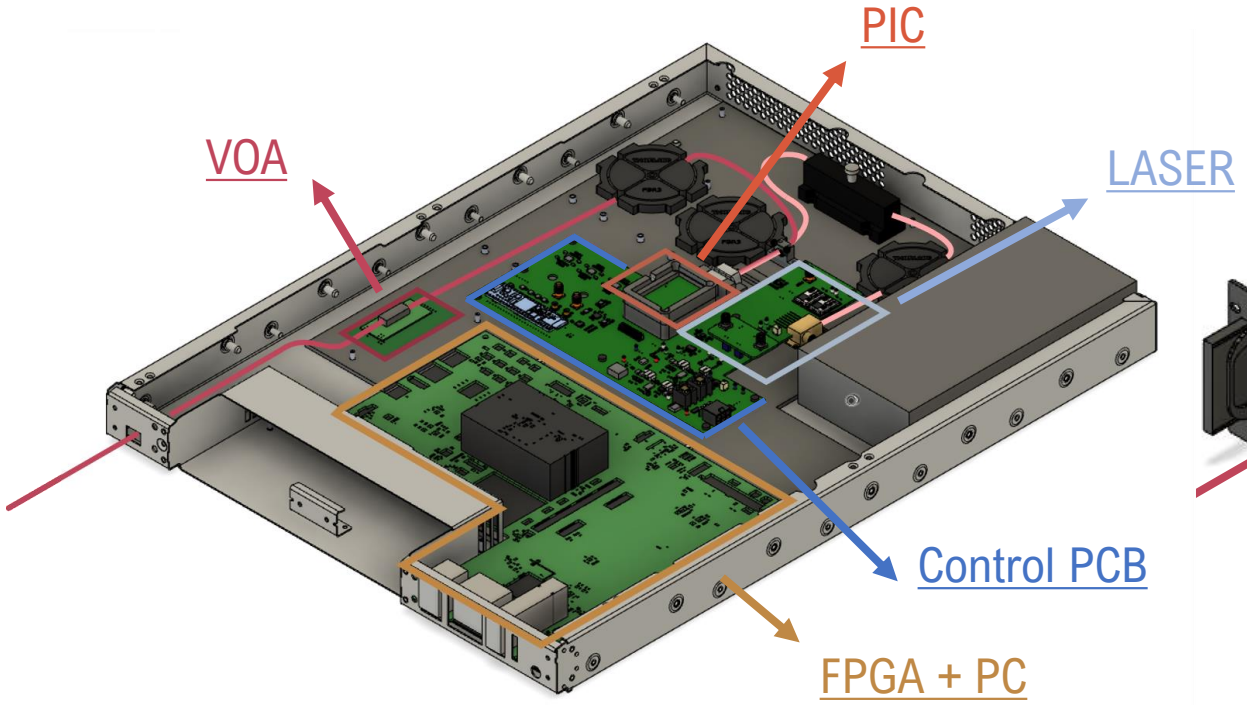

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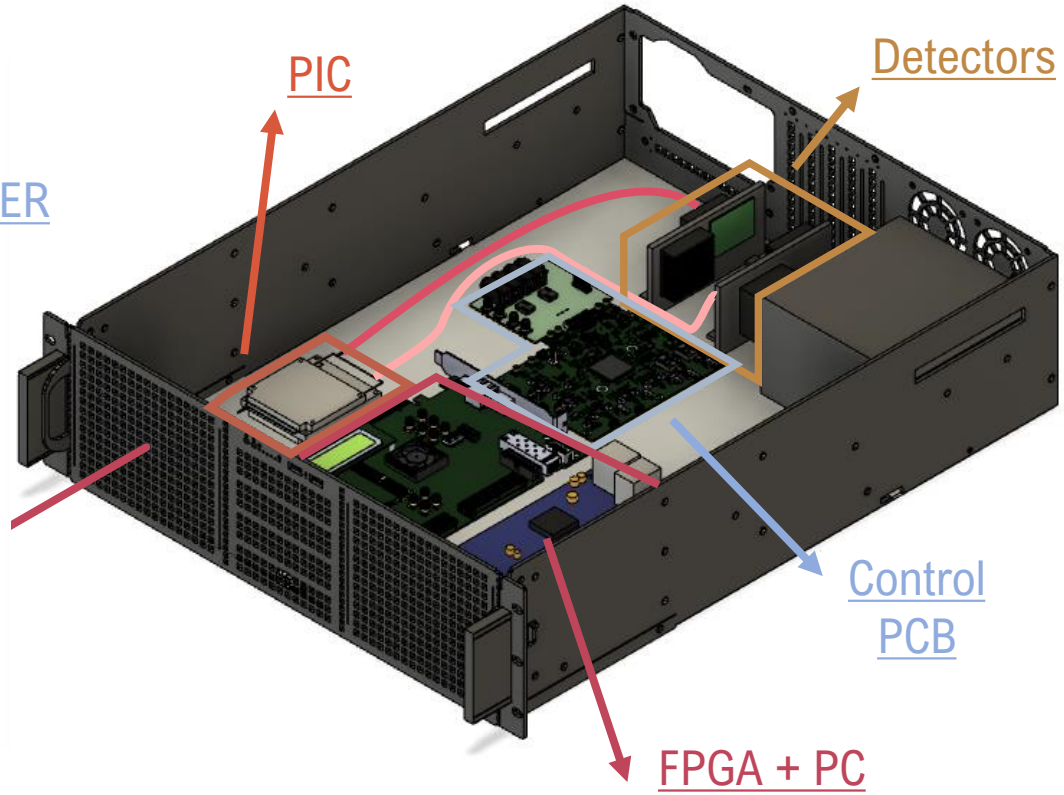
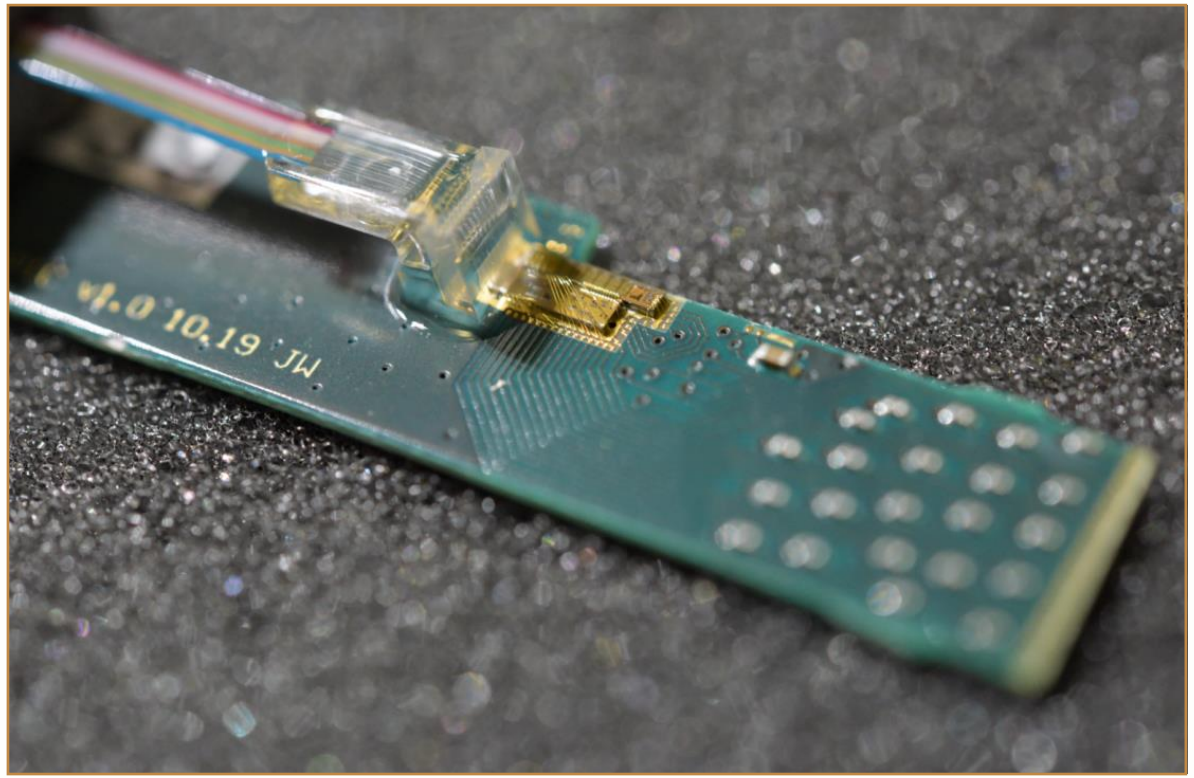


Sender PIC



Picture: Sax, R. et al. (2023) “High-speed integrated QKD system,” Photonics Research.

Silicon based.

In collaboration with Sicoya GmbH

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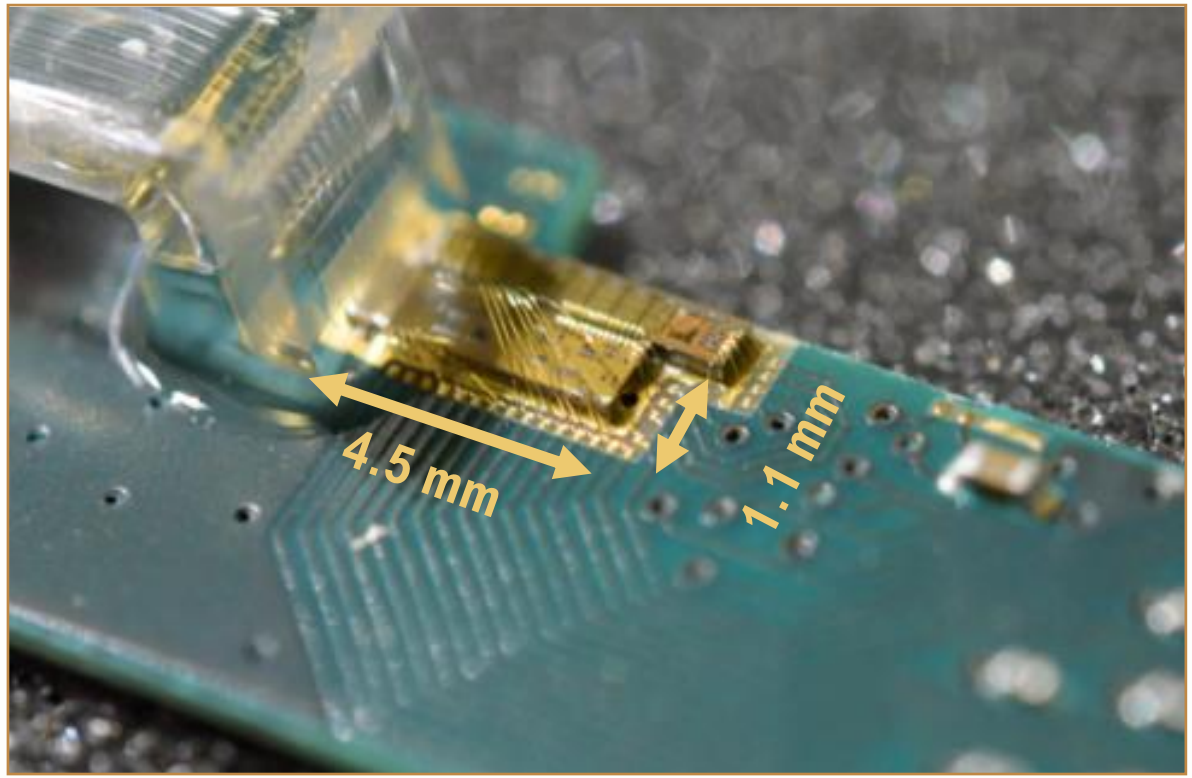

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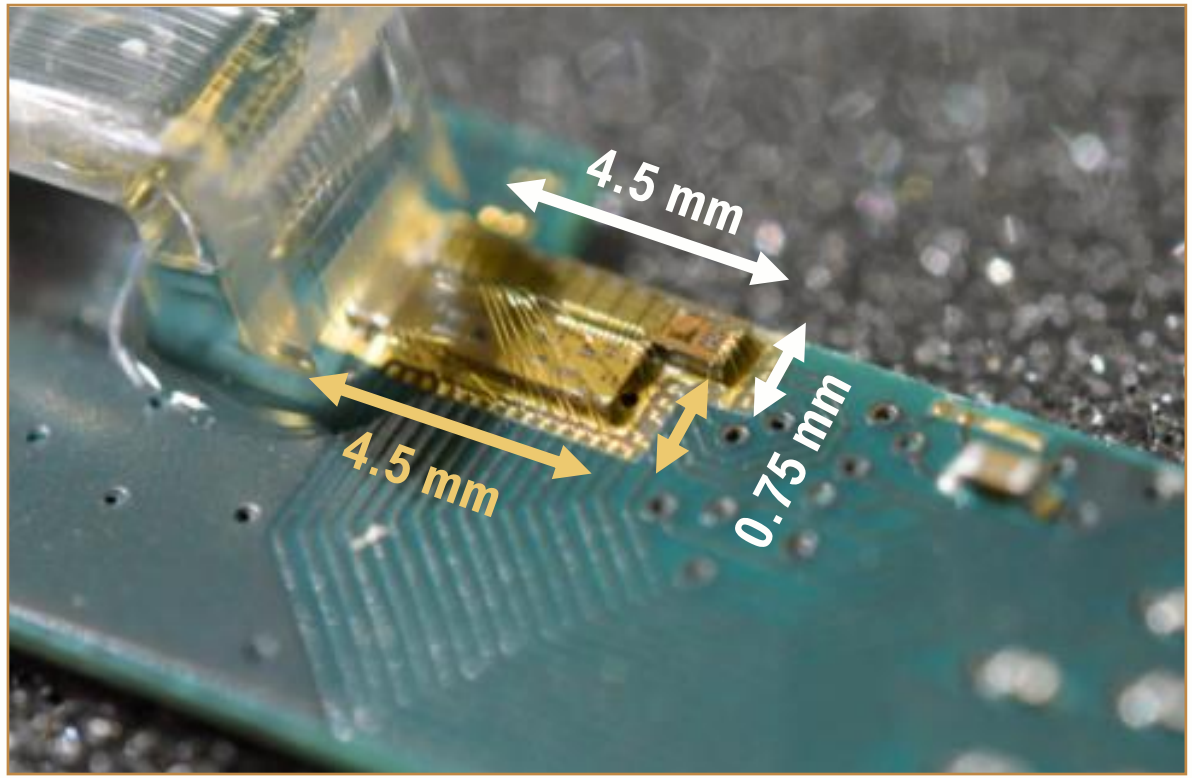
- PIC (Photonic Integrated Circuit)

Sender PIC



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- PIC (Photonic Integrated Circuit)
- EIC (Electronic Driver Integrated Circuit)

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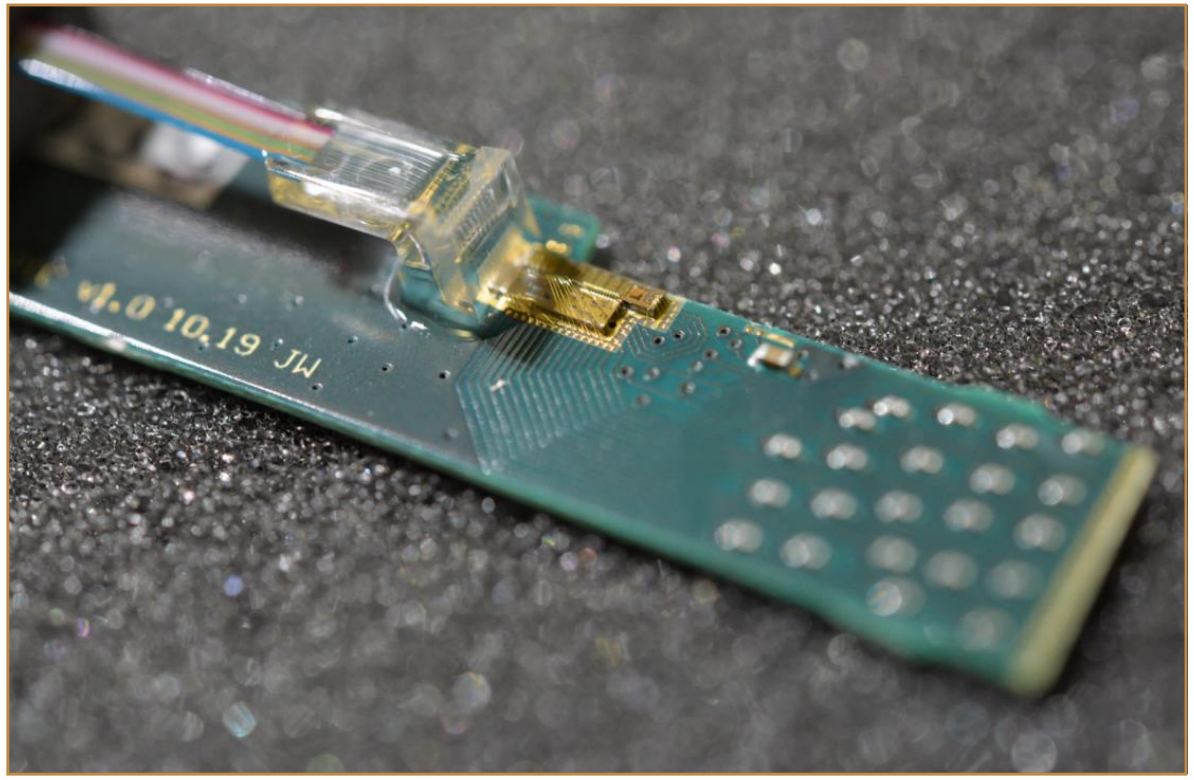

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- PIC (Photonic Integrated Circuit)
- EIC (Electronic Driver Integrated Circuit)
- PCB - 4cm x 1 cm

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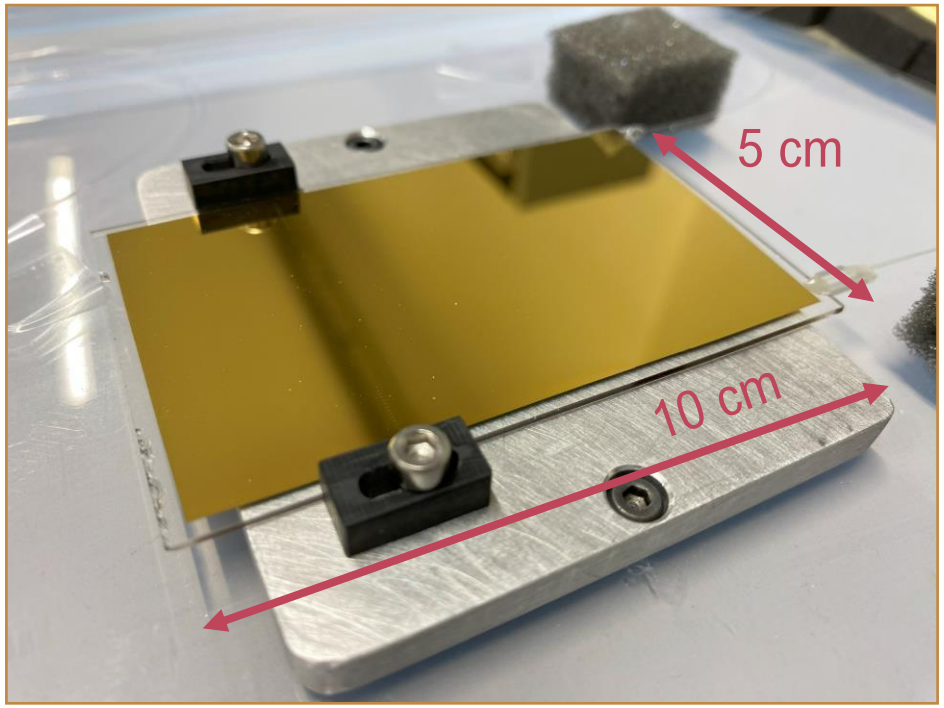
Receiver PIC



Silica based

In collaboration with CNR-IFN - Group of Roberto Osellame

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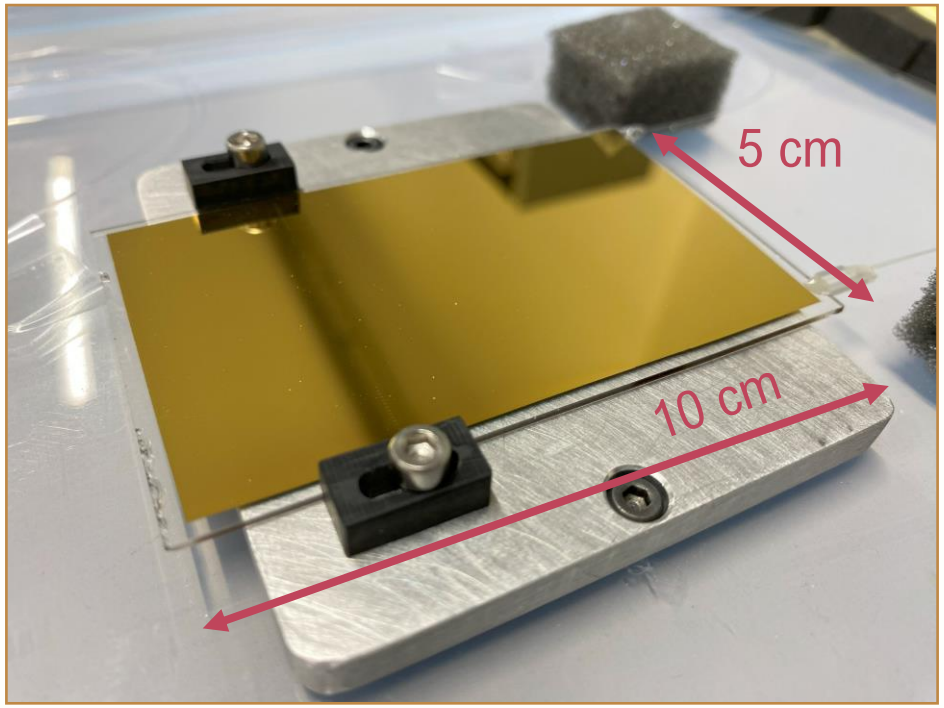

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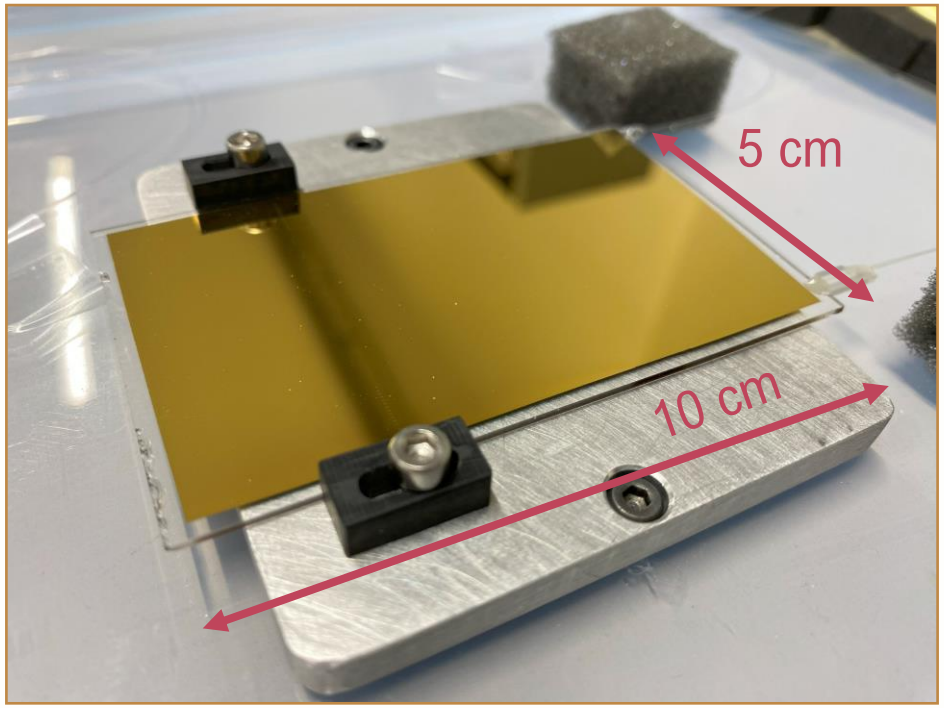

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Polarization Insensitive

Giacomo Corrielli, Simone Atzeni, Simone Piacentini, Ioannis Pitsios, Andrea Crespi, and Roberto Osellame, "Symmetric polarization-insensitive directional couplers fabricated by femtosecond laser writing," Opt. Express 26, 15101-15109 (2018)

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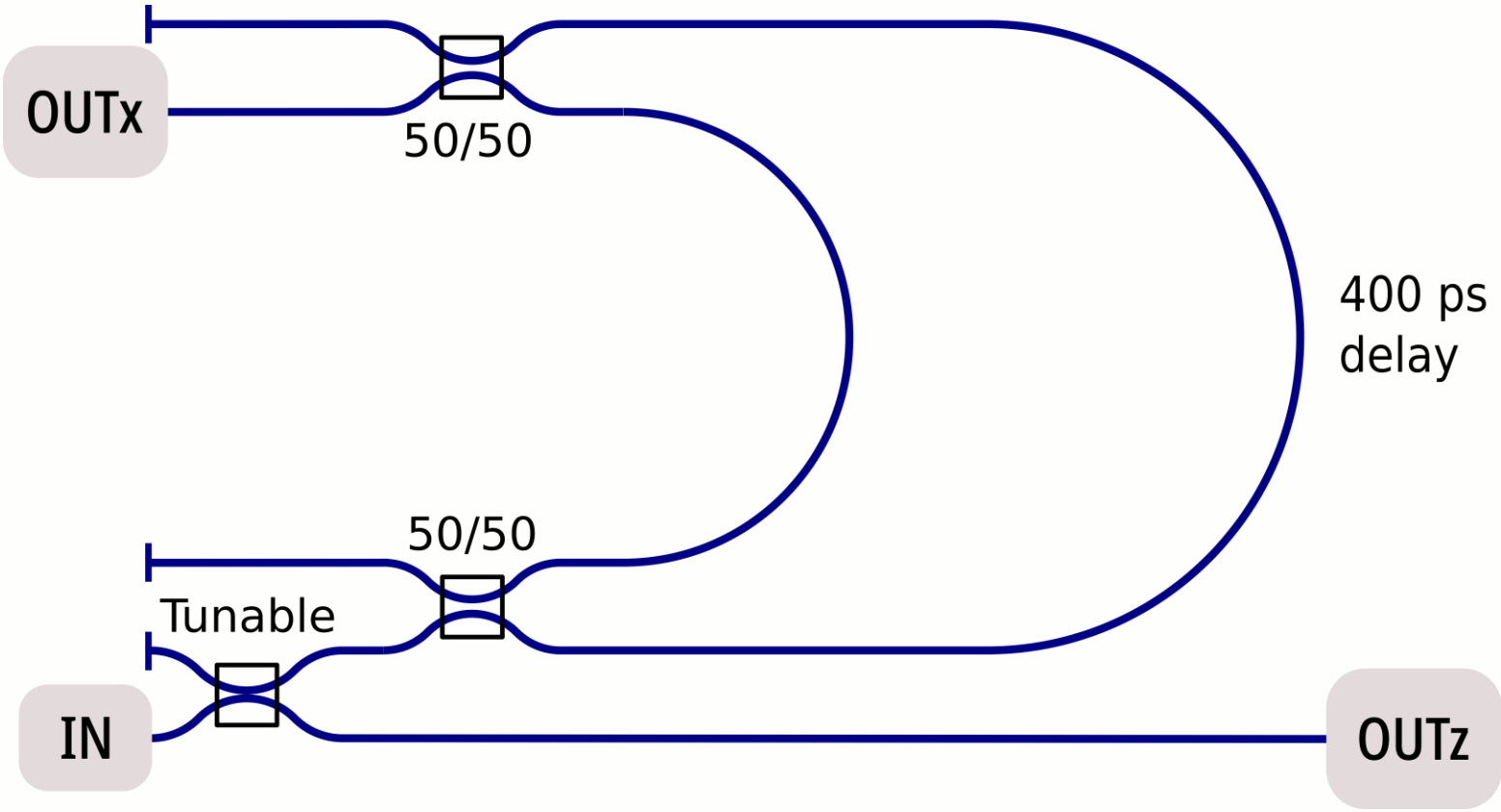

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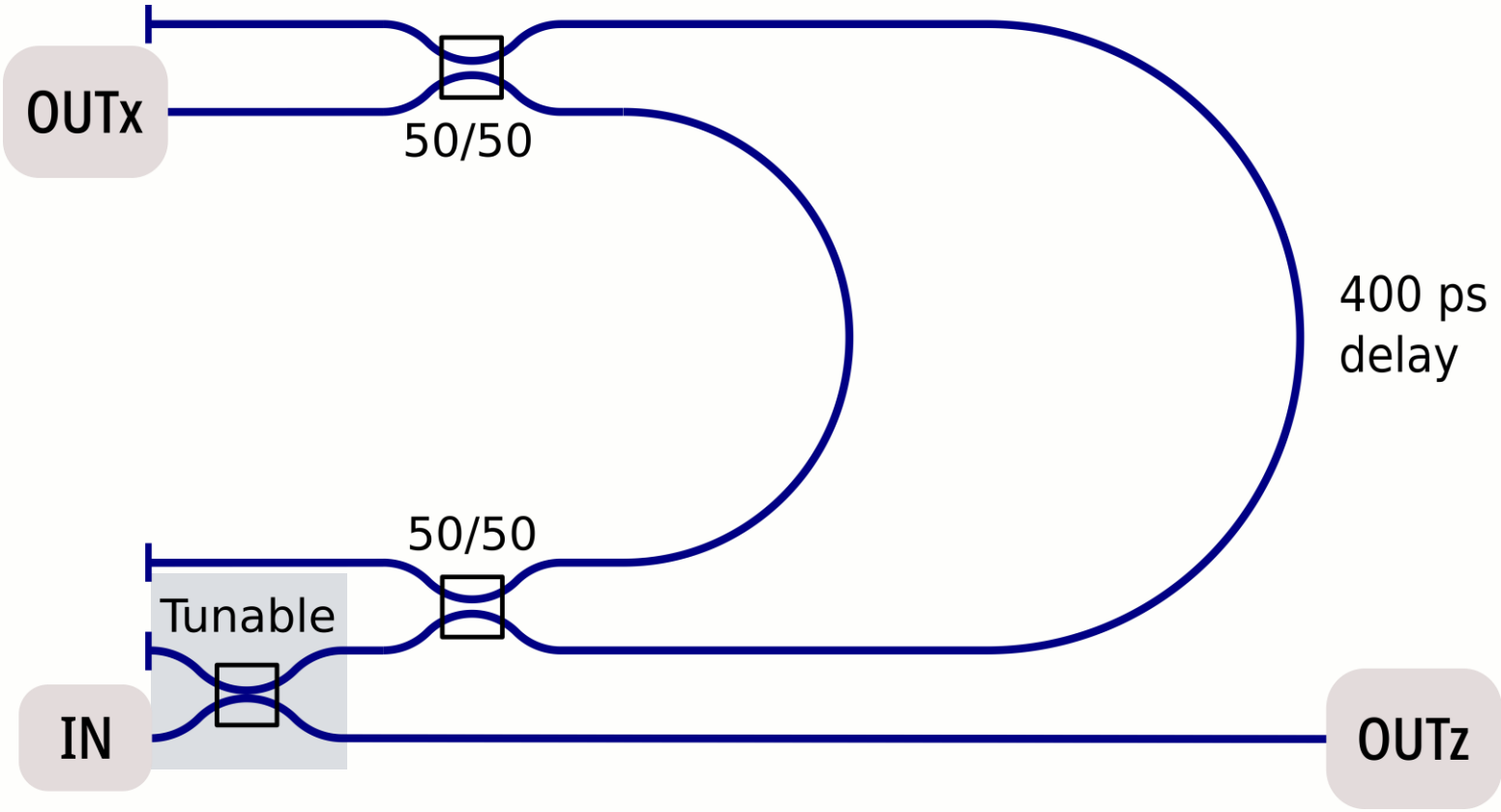

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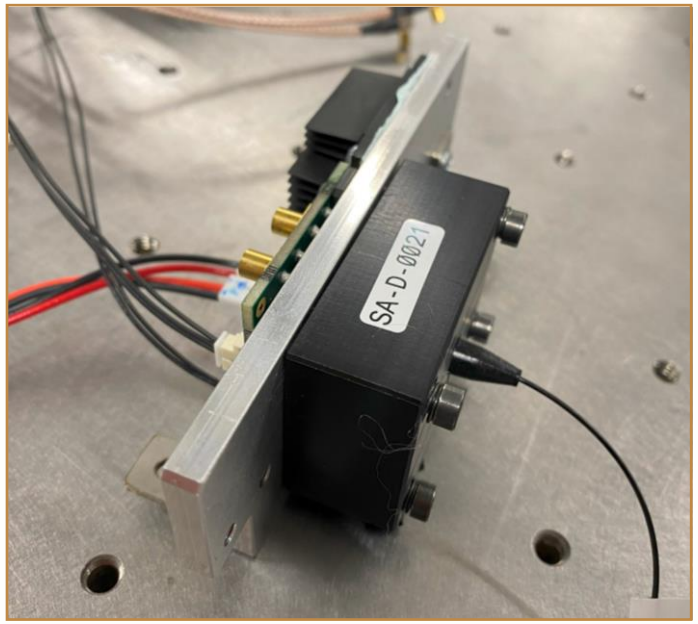
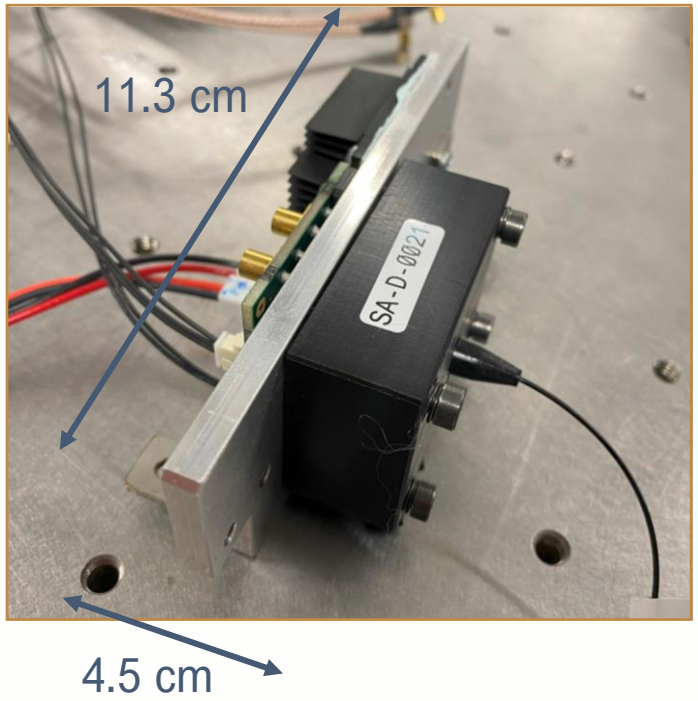
Detectors

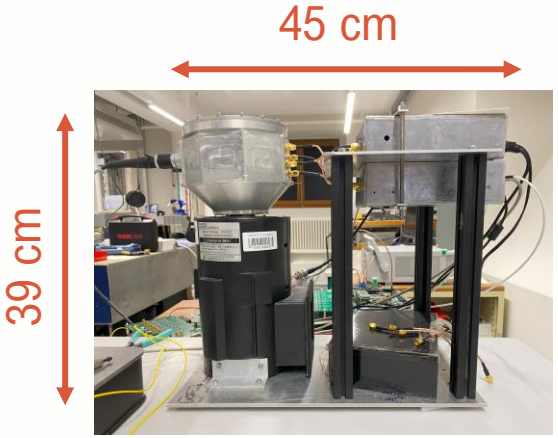
InGaAs NFADS

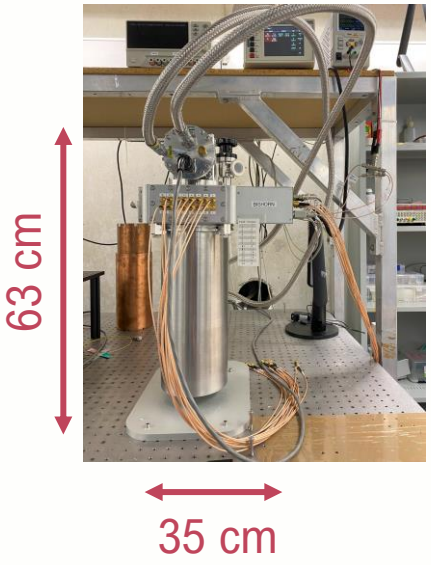


Detectors

InGaAs NFADS







+ compressor

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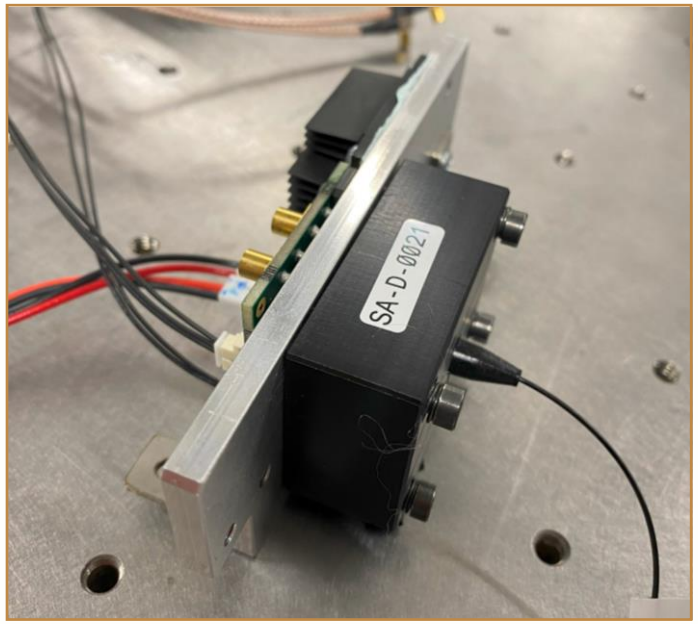
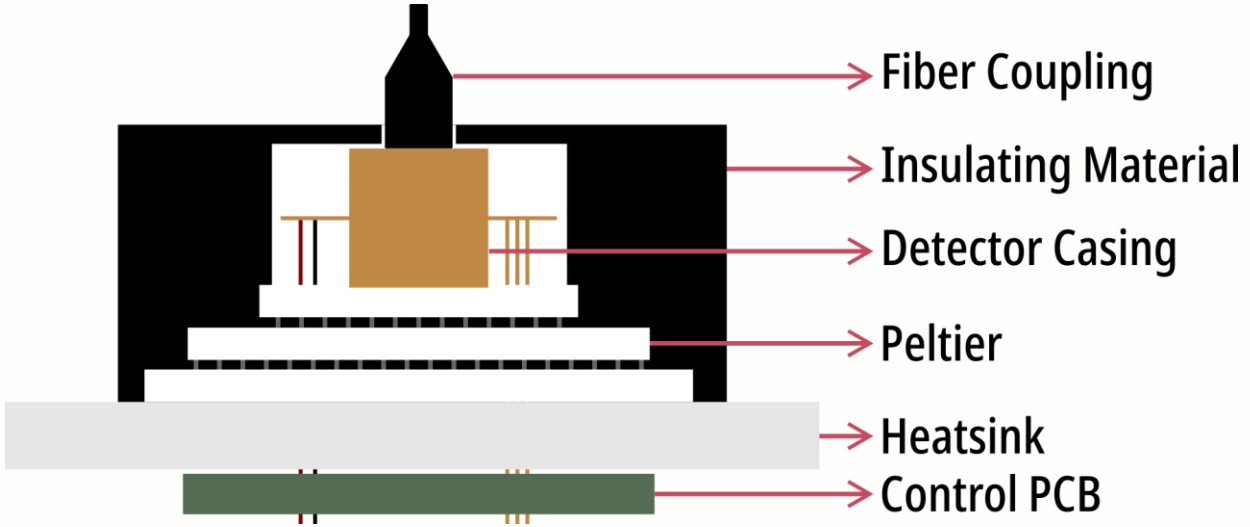
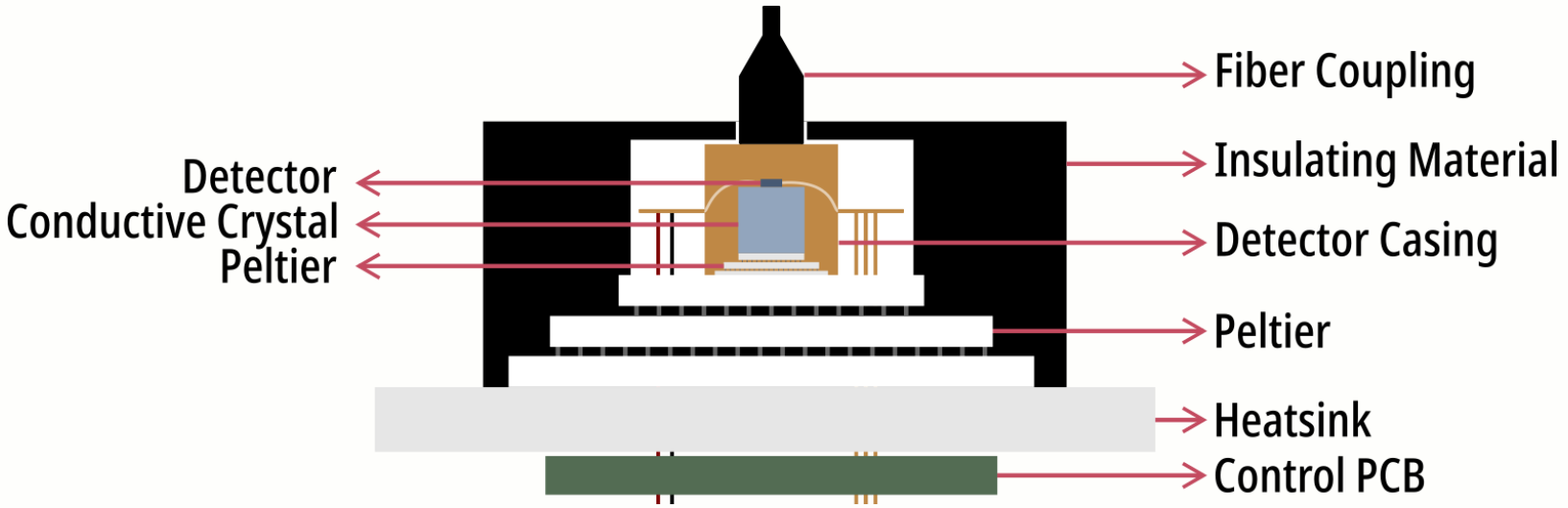
Detectors





Detectors



Detectors

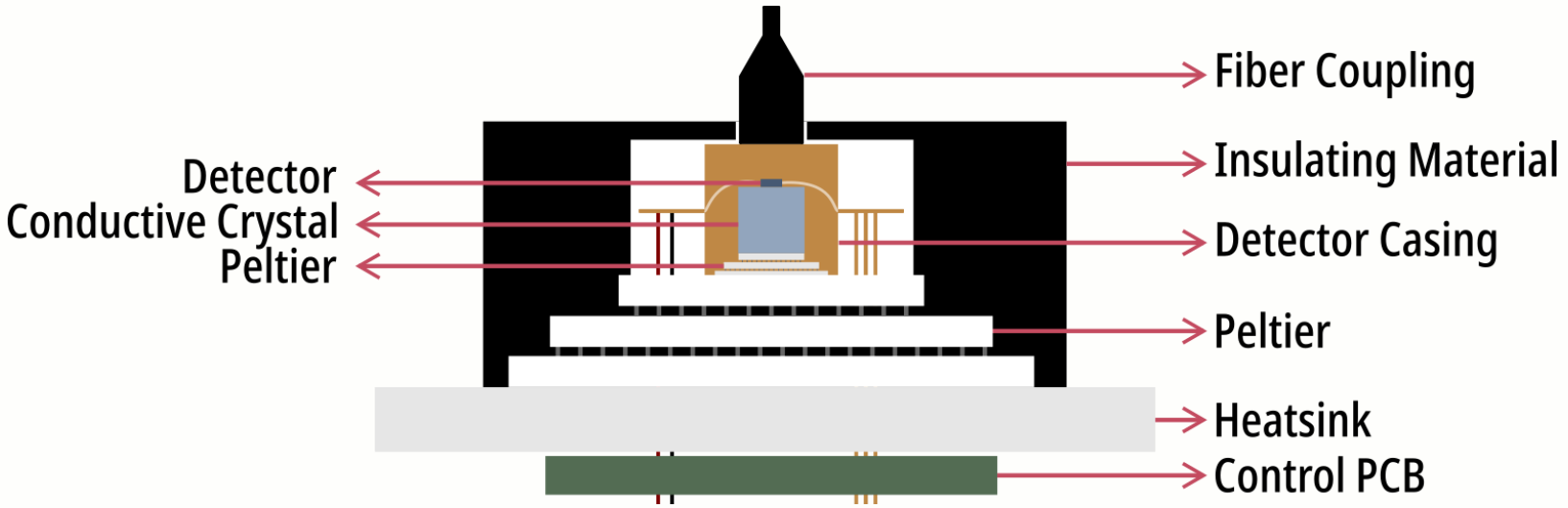
T = -50˚C

PDE = 25%

DCR < 600cps

APP = 3%

Jitter = 120ps



Outlook

What's missing?

Outlook

What's missing?

- **BOB PIC** (currently in production)
- Finalize **mechanics** i.e. boxes, holders, etc…
- **Optimize Alice PIC** parameters with BOB PIC
- **Optimize NFADs** workpoint.

First Results

$QBER_Z = 1.8\%$

$QBER_X = 3\%$

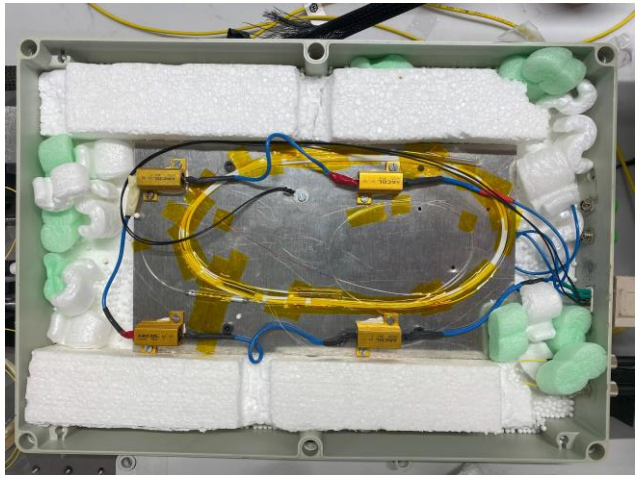
@30dB

First Results

$QBER_Z$ = 1.8%

$QBER_X$ = 3% → w/ temporary fiber based Imb-I

@30dB

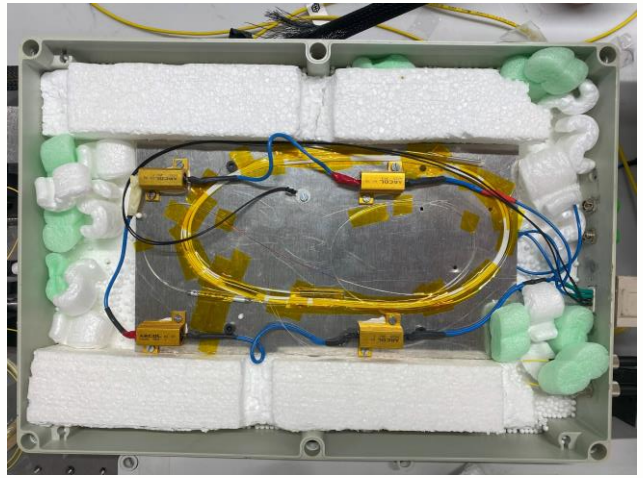


First Results

$QBER_Z$ = 1.8%

$QBER_X$ = 3% → w/ temporary fiber based Imb-I

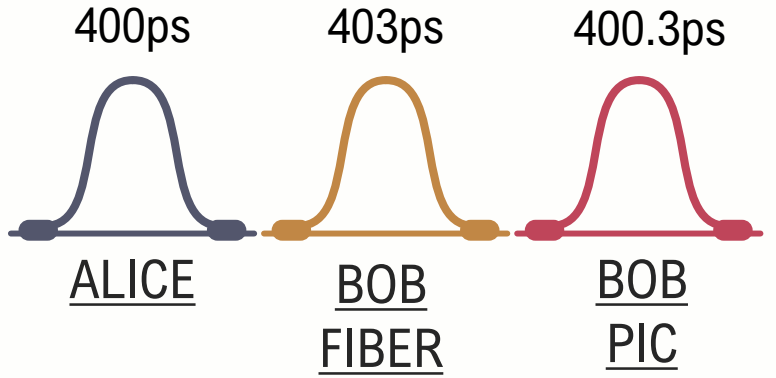
@30dB



Delay diffrence:

3ps → Alice (PIC) & Bob (FIBER)

0.3ps → Alice (PIC) & Bob (PIC)



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First Results

$QBER_Z = 1.8\%$

$QBER_X = 3\%$

@30dB

$QBER_Z = 3.6\%$

Previous Integrated Experiment

Sax, R. et al. (2023) “High-speed integrated QKD system,” Photonics Research.

Special thank you:

Rebecka Sax

Alberto Boaron

Hugo Zbinden

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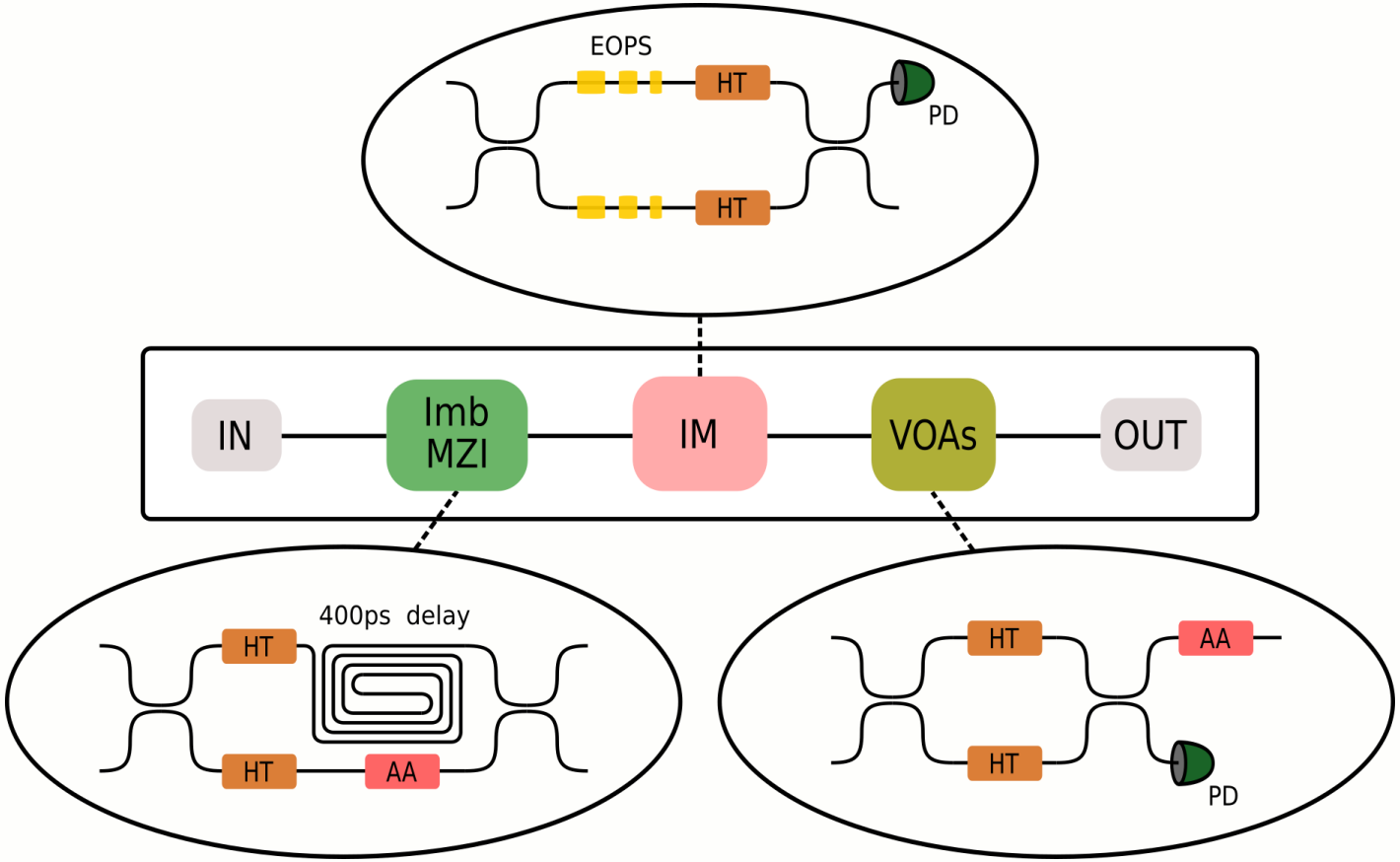
Sender PIC



Adapted from: Sax, R. et al. (2023) “High-speed integrated QKD system,” Photonics Research [Preprint]. Available at: https://doi.org/10.1364/prj.481475.