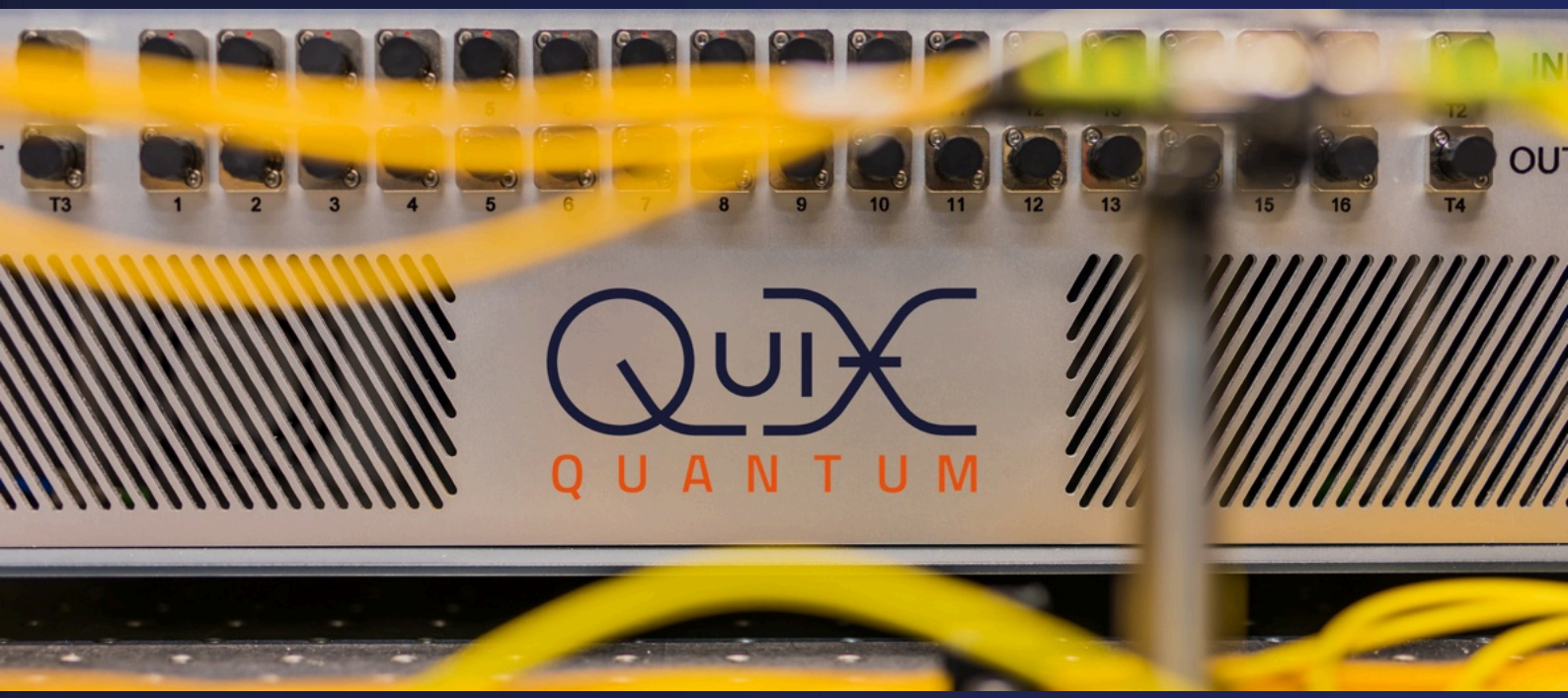

INFORMATION PROCESSING AT THE SPEED OF LIGHT

ALQUOR®

WHITE PAPER

QUIX QUANTUM

Hengelosestraat 500
7521AN Enschede
The Netherlands

+31 (0) 53 48 36 444
sales@quixquantum.com

www.quixquantum.com

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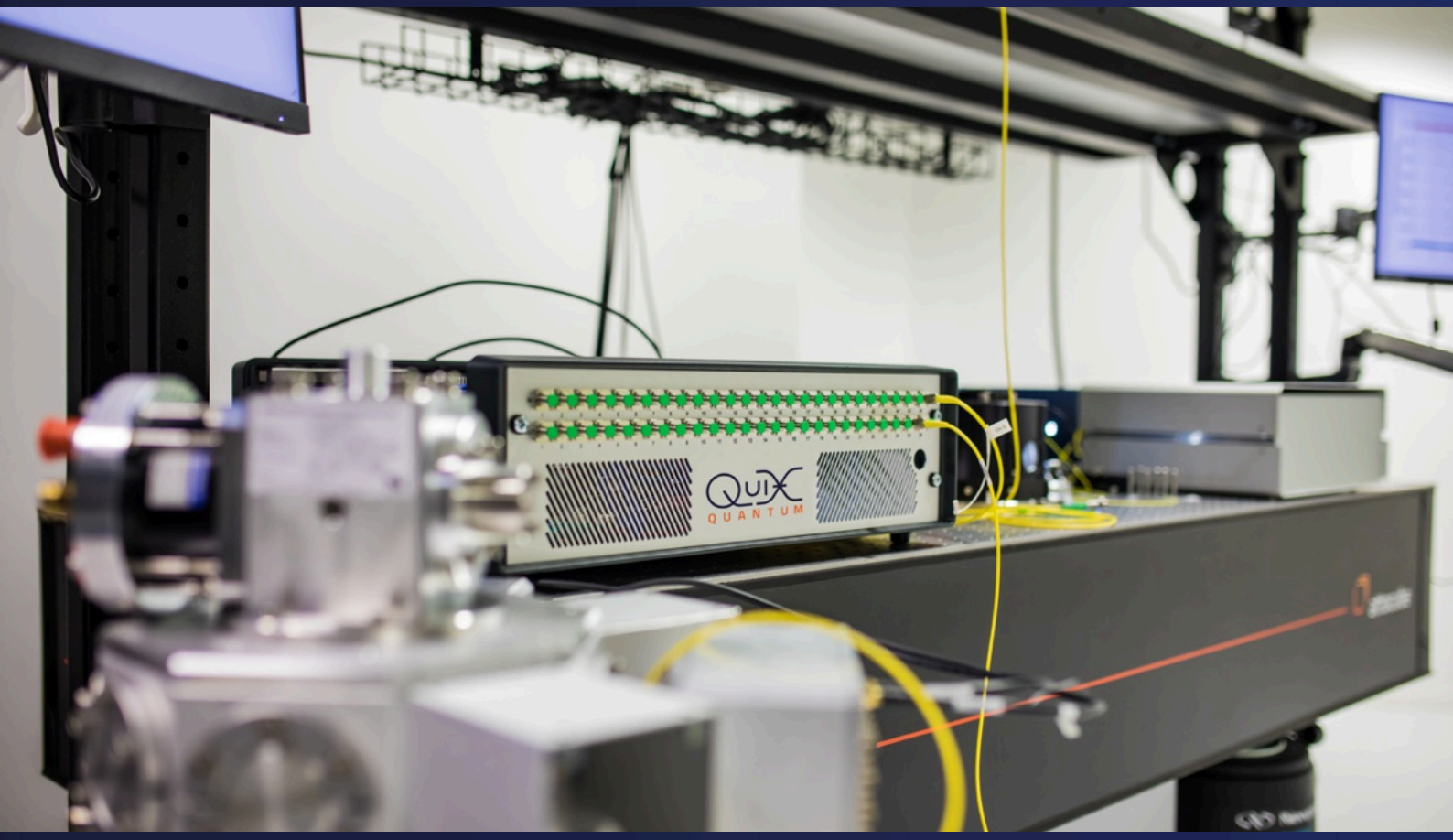


Alquor® Quantum Photonic Processor

The quantum photonic processor Alquor is a ***photonic integrated programmable multiport interferometer.*** It represents the most powerful tool on the market for photonic quantum information processing. Alquor utilizes integrated photonics technology, where the miniaturization allows efficient scaling, phase stable operation and provides the lowest propagation loss using the TriPleX silicon nitride platform (read more in our "Silicon Nitride building blocks" white paper).
QuiX Quantum is therefore the world-wide market leader in photonic integrated quantum photonic processors with the largest number of ports, lowest transmission losses and best performances.

What is a *programmable multiport* interferometer?

It is a device that can implement any linear optical transformations up to the size of the interferometer (the size given by the number of inputs that is also equal to the number of outputs). The interferometer acts on multiple input optical signals by combining them together (i.e., interfering them) in a controlled way, defined by the user. Alquor offers all-to-all connectivity, which means that each input optical signal can interfere with any other input optical signal before exiting the interferometer. More details are provided in the section "Operation Principle".

What does *photonic integrated* mean?

The term *photonic integrated* refers to the integration of photonic components onto a single chip, known as a photonic integrated circuit (PIC), where optical waveguides are used to carry the light. A traditional implementation of a multiport interferometer would involve bulk and free-space optical components, i.e., mirrors, glass beam splitters and waveplates with need for re-alignment. Alquor offers a compact and scalable implementation of an interferometer with phase stable operation, low propagation losses, and programmability. Its optical waveguides, which guide optical signals on the chip, are realized with TriPleX technology, which provides the highest numbers of components for the lowest losses.

What are the key advantages of Alquor?

Alquor is a turn-key solution to enhance and speed-up quantum optics experiments. While free space experiments are unstable and require constant realignment, Alquor is a stable and robust alternative that requires minimal maintenance, therefore minimizing the downtime and preparation routine for an experiment. Thanks to Alquor's programmability and PC interface, the sequential implementation of various linear optical transformations no longer requires hours of tedious manual lab work, but can be done in seconds with just a few lines of code. The actual measurement time, i.e., data collection, of your experiment is therefore maximized. In addition, Alquor's small form factor allows it to fit easily into dense laboratory facilities.

Alquor comes from a team of experts in integrated optics and quantum physics with excellent academic training and extensive laboratory experience. It was designed as the perfect tool to accelerate quantum optics research.

Technical details about the quality and performance of Alquor can be found in the paper Taballione, C., et al. *"20-mode universal quantum photonic processor."* Quantum 7 (2023): 1071., or by contacting us at sales@quixquantum.com.

Applications

Quantum Information Processing

Alquor can be used for various applications in the field of quantum information processing (QIP). Of course, Alquor alone is not enough; it can only perform as part of a larger set-up that includes, for example, single photon sources and single photon detectors, or a phase-locking solution. Below is a list of linear optics QIP protocols that are possible to run on Alquor-like devices.
These scientific papers are intended primarily as inspiration.

1. Single- and multi-qubit manipulation [1, 2]
2. Multi-photon interference [3-7]
3. Boson sampling [8,9]
4. Quantum walks [10-12]
5. Linear optics quantum gates [13-15]
6. Shors algorithm [16]
7. Variational eigenvalue solver [17]
8. Quantum phase estimation [18]
9. Generate molecular vibronic spectra [19]

Quantum Computing

Ultimately, Alquor and its further developments can we used as the quantum processing unit (QPU) of a photonic quantum computing system.

Quantum computing is a new computing paradigm that promises to solve problems that are practically unsolvable for classical computers. It is therefore expected to have a dramatic impact on various fields, including cryptography, optimization, materials science and chemistry. Moreover, quantum computing opens up new possibilities in machine learning and artificial intelligence. Alquor enables the miniaturization and scalability of photonic quantum computers, by integrating the QPU on a single chip, reducing size and complexity while improving stability and performance. This enables the development of more powerful and practical photonic quantum computers. So far, Alquor can be used to realize small-scale special-purpose quantum computers, as the one offered by QuiX Quantum via cloud access. In the future, with the development of new components, QuiX Quantum will provide universal quantum computing capabilities following both the measurement-based paradigm natively and gate-based via a compiler.

Alternatives

While the applications mentioned so far are what Alquor is tailormade for, other alternative applications are possible to tackle with Alquor as well. It should be noted however that Alquor is not a turn-key solution for those applications and specialized additional equipment or extensive customization of Alquor itself would be required.

Quantum Cryptography

The best-known example of quantum cryptography is Quantum Key Distribution (QKD), which provides an information-theoretically secure solution to the key exchange problem. The security of QKD is based on the laws of quantum mechanics and makes it resistant to all kinds of attacks, even attacks from quantum computers. Unlike post-quantum cryptography, QKD is not based on the supposed difficulty of certain mathematical problems but is inherently secure. The path to miniaturized quantum communication systems of increasing complexity and enhanced functionality is paved by photonic integration.

Quantum Random Number Generation

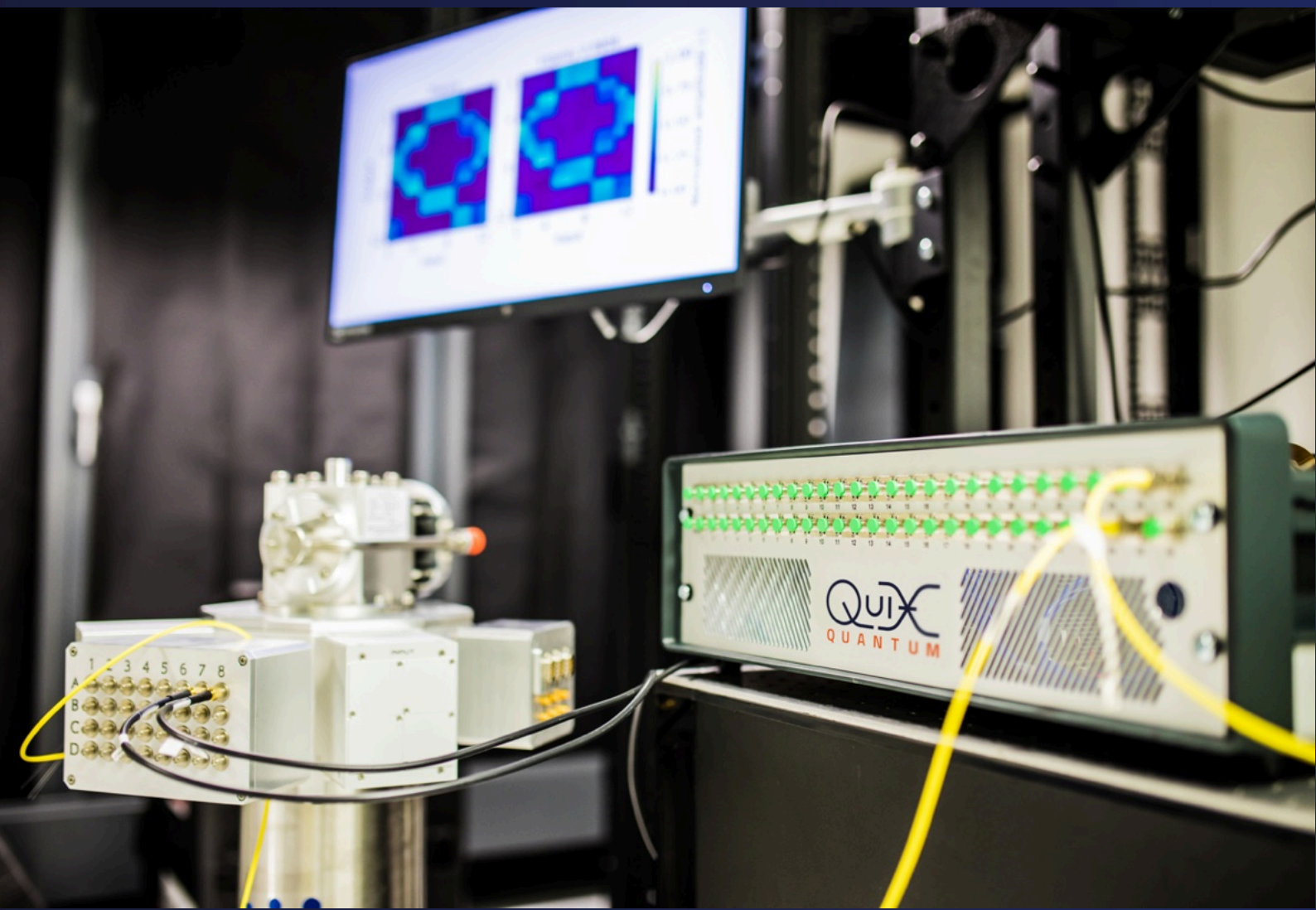
True random numbers play an important role in many applications, for example cryptography and simulation. Since quantum mechanics is fundamentally and inherently non- deterministic (i.e., probabilistic), Quantum Random Number Generation (QRNG) is the only known method for generating true randomness. Alquor exploits the probabilistic nature of quantum mechanics and can serve as a robust, stable, and flexible entropy source for QRNG. This provides an unparalleled level of security by generating true random numbers that are fundamentally impossible to predict or replicate.

Optical Network Switching

As the demand for data transmission continues to grow exponentially, there is an increasing need for high-speed and low-latency optical interconnects in data centers, HPC environments, and telecommunication networks. When used as an optical circuit switch (OCS), Alquor provides high bandwidth, minimal latency, and extremely low loss. In addition, Alquor's large transparency window makes it an excellent choice for switching both classical and quantum data in optical networks.

Optical Power Grid Distribution

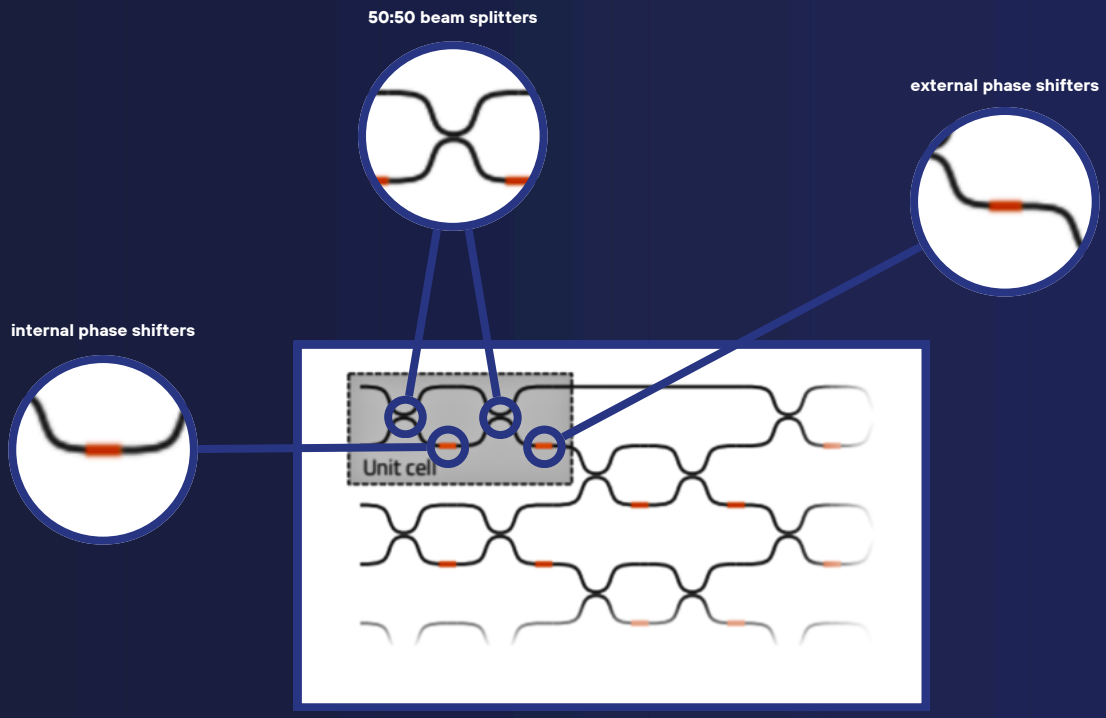
The ability of distributing an incoming optical signal in a reconfigurable manner across multiple output channels, with the ability to control the power distribution profile and the time delays between the outputs is a crucial feature for other quantum computing technologies. Being an integrated multiport interferometer, Alquor provides a high-quality control over the coherent superposition of all the optical signals with an all-to-all connectivity, with the advantage of compactness and room-temperature operation.



Operation Principle

Describing the operation principles of Alquor starts with the workings of its unit cell, the main building block of the device. The unit cell consists of a Mach-Zehnder interferometer (MZI) acting as a tunable beam splitter, formed by two 50:50 beam splitters and an internal phase shifter between them, as well as an external phase shifter, as it is shown in the figure below (phase shifters marked in orange). More details about the construction and operation of the tunable beam splitter and phase shifter can be found in our white paper "Silicon nitride building blocks".

The two phase shifters serve different roles: the internal one changes the amplitude ratio of the light on the two outputs of the unit cell and the external one changes the phase between the two outputs of the unit cell.
To build a photonic processor, many unit cells are combined in a specific pattern enabling the implementation of any arbitrary linear optical transformation between multiple input optical signals. The pattern is chosen such that every input optical signal can interfere with any other input optical signal and exit the chip from any output, ensuring a maximal interaction between all the optical signals.



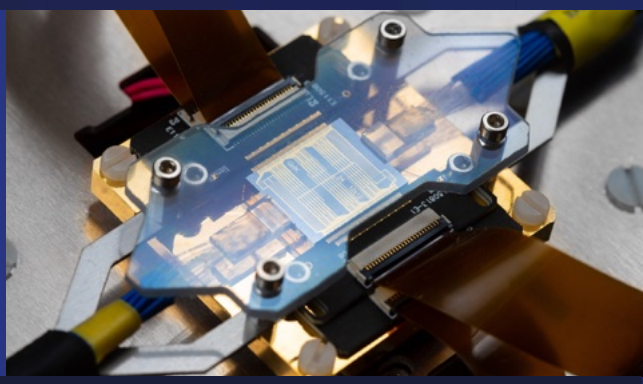
Unit cell: the smallest repeating structure.

The Alquor® System

Alquor is offered in different versions, see our Data Sheet for more info.
Its main components are described below.

Photonic Assembly

Inside Alquor sits a fully packaged photonic chip. The chip sits on a sub-mount for mechanical stability and is electronically connected to a PCB. Photonic connection is realized by optical fiber arrays attached to the chip.

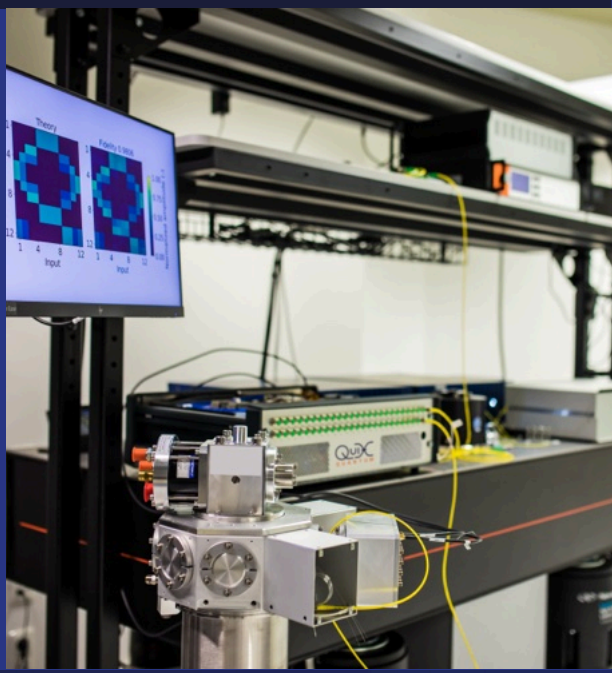


Control Unit

The photonic assembly is embedded in a control unit, which offers easy access to optical input and output ports, a thermally controlled environment and a PC interface. Our control software implemented in Python allows for easy implementation and reconfiguration of any linear optical transformation with just a few lines of code. Alquor comes fully calibrated ensuring turn-key operation.

System Integration

Alquor is designed to integrate seamlessly into photonic experimental setups. The recommended equipment to run experiments on Alquor comprises fiber-coupled light sources (single-photon sources, CW lasers, etc.), a demultiplexing mechanism (a DMUX or fiber switch), a phase locking system (if required for the experiment) and a detection system (PD arrays, SNSPDs, etc.). Alquor can be easily upgraded by replacing the internal photonic assembly and keeping the same control unit, ensuring a smooth and quick advancement of your experiments



Want to discuss more?

We are always happy to address your needs and discuss the usability of Alquor for your specific application. Alquor is a versatile tool, and the possibilities of integrated photonics are manifold! Please don't hesitate to **contact us**.

WWW.QUIXQUANTUM.COM

SALES@QUIXQUANTUM.COM

HENGELOSESTRAAT 500
7521AN ENSCHEDE

+31 (0) 53 48 36 444

About QuiX Quantum

QuiX Quantum is the leading photonic quantum computing hardware company, driving innovation with proven quality in the development of its Universal Quantum Computer. The first system, already sold and contracted for delivery, underscores the impact of QuiX Quantum's market-leading hardware and renowned quality. This strong technological foundation positions the company to build the most powerful quantum computers. With five offices across Europe, QuiX Quantum continues to push the boundaries of quantum technology while serving a growing global customer base.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