nVent SCHROFF

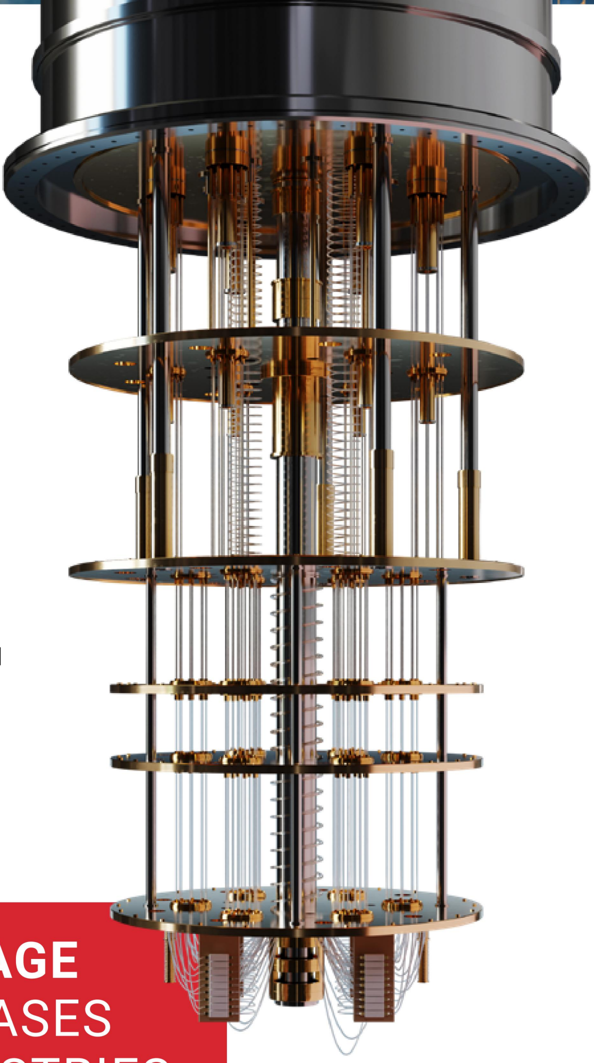
Commercializing & Scaling QUANTUM COMPUTING

from a Control Systems Perspective

Quantum computing requires harnessing the laws of quantum mechanics to solve problems beyond the scope of what a classical computer can handle. It is a broad field with many sub-fields and supporting technologies inside of it. With that in mind, we'll scratch the surface on where the quantum computing industry is today, where it's going, and how modular, open platforms are providing a foundation for scalable quantum computing control systems.

We connect and protect

QUANTUM COMPUTING, Today & Beyond



Today, quantum computing systems are mostly found in research and educational settings. There are preliminary applications in areas where machine learning, simulation, and optimization are critical for industry advancements (e.g., chemistry, pharmaceuticals, weather, and finance). For example, pharmaceutical companies are looking for analytical methods to simulate interactions between different molecules or electronic orbitals of atoms, and climate scientists are looking for more advanced and accurate atmospheric warning signs ahead of major storms.

Quantum computers are expected to achieve quantum utility in the next one to three years. At that point, these systems will be able to solve theoretical problems that classical computers cannot. In two to four years, these systems are expected to reach the quantum advantage stage, where they can address real-world use cases and pain points across industries. Long term, the goal is to create a fault-tolerant quantum computer that corrects computational errors and provides trusted results at scale. Errors are natural when using quantum mechanics as the basis for computation.

THE QUANTUM ADVANTAGE STAGE — ADDRESS REAL-WORLD USE CASES AND PAIN POINTS ACROSS INDUSTRIES

While there are many
enabling quantum computing technologies,
several show promise in the near future.

SUPERCONDUCTING PROCESSORS

With superconducting processors, qubits are made using superconductive materials, like aluminum, that exhibit zero resistance at very low temperatures. While aluminum demonstrates superconducting properties in temperatures around 1 Kelvin (K), superconducting qubits require much colder operating environments (i.e., 10 to 20 mK) to overcome thermal noise. In an electronically noisy environment, it is nearly impossible to distinguish and measure quantum phenomena.

In this approach, bounded electrons (i.e., Cooper pairs) flow through a thin layer of insulation between two superconductors called a Josephson junction. These junctions are engineered to only permit passage via quantum tunneling, so engineers can observe macroscopic quantum effects. These effects are only observable when the electromagnetic environment around the junction can be tuned to a pre-determined operational range using precise electrical signals. Along with biasing the device into proper operating conditions, these pulsed signals also write information for the qubits, mediate interactions, and read out quantum states alongside a precise measurement system.

PHOTONIC PROCESSORS

With photonic processors, photons store, process, and manipulate quantum information. Properties like polarization and phase of photons represent qubit state, and the system is controlled using beam splitters, phase shifters, mirrors, and other photonic elements. Scientists and engineers are consistently developing and improving complex photon sources to refine this technology. Though manufacturing photonic processors is simpler than manufacturing other processors, and they can operate at room temperature, this technology faces challenges at scale. Relevant chip topologies are less flexible, qubit gates are harder to measure independently, and they process a bit slower because creating entangled photons takes more time.

ION TRAP PROCESSORS

In quantum computing, these devices use electromagnetic fields to trap charged atoms (i.e., ions) and use their quantum states for computations. Each ion acts as a qubit. Using electromagnetic control mechanisms, qubits can be initialized, manipulated, and read out. With long coherence times, this technology is promising in the pursuit of fault-tolerance at scale. Coherence time refers to the limited amount of time that is statistically available to read correct information from a qubit, without having information lost to the environment.

NEUTRAL ATOM PROCESSORS

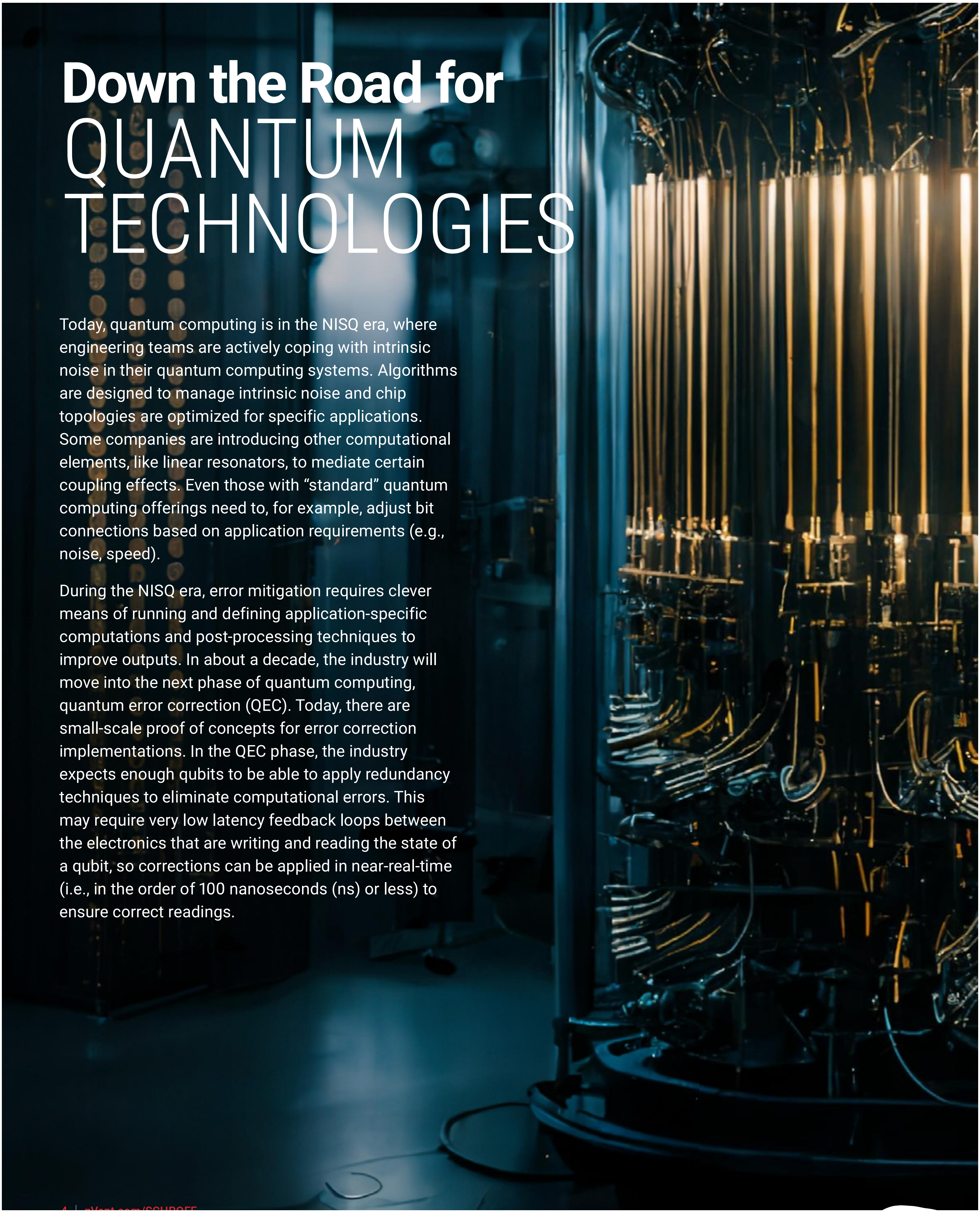
In contrast to ion trap processors, atoms that have no net electric charge act as qubits with neutral atom processors. Also in contrast, atoms are suspended using optical traps set by lasers rather than leveraging electromagnetic control. Here, quantum information processing occurs using controlled interaction between neutral atoms. Neutral atom processors accommodate more qubits packed closely together, which can reduce electromagnetic interactions.

QUANTUM ANNEALERS

This technology leverages annealing to place qubits at an absolute energy minimum, which corresponds to the near-optimal solution. Annealing is the physical process of heating a material and slowly cooling it to identify a stable state. This technique is useful when the task is to find the best solution among a large solution set (e.g., complex scheduling, materials selection). Quantum annealers can handle a much larger number of qubits than today's gate-based systems; however, use cases are limited.

Even with many to choose from, there is no single technology that is positioned to "win over" the market in the next few years (i.e., in the noisy intermediate-scale quantum (NISQ) era). Different quantum technologies work better for different applications. In other words, these technologies aren't competing—for now.

Engineering advancements, rather than scientific advancements, are needed to solve the bottleneck of cost scaling for higher qubit counts, more channels, and more robust cryogenic systems (for superconducting processors). However, the first step in this process is improving qubit coherence time versus gate speeds, which leads to an increase in gate fidelity. Gate fidelity can be indicative of the success rate of a computational gate. Computational gates are computational operations within a qubit or between two qubits. Manufacturing processes, material purity, qubit design, noise sources in the system, and quantum processing unit (QPU) design all impact qubit coherence time. Gate speeds are predominately impacted by the QPU and qubit design, but they are also influenced by the analog output capabilities of the electronics used for qubit control. Engineering teams are in the process of increasing the quality of qubits themselves and reducing error rates. Increasing the number of qubits without fidelity improvements leads to bigger computational errors.



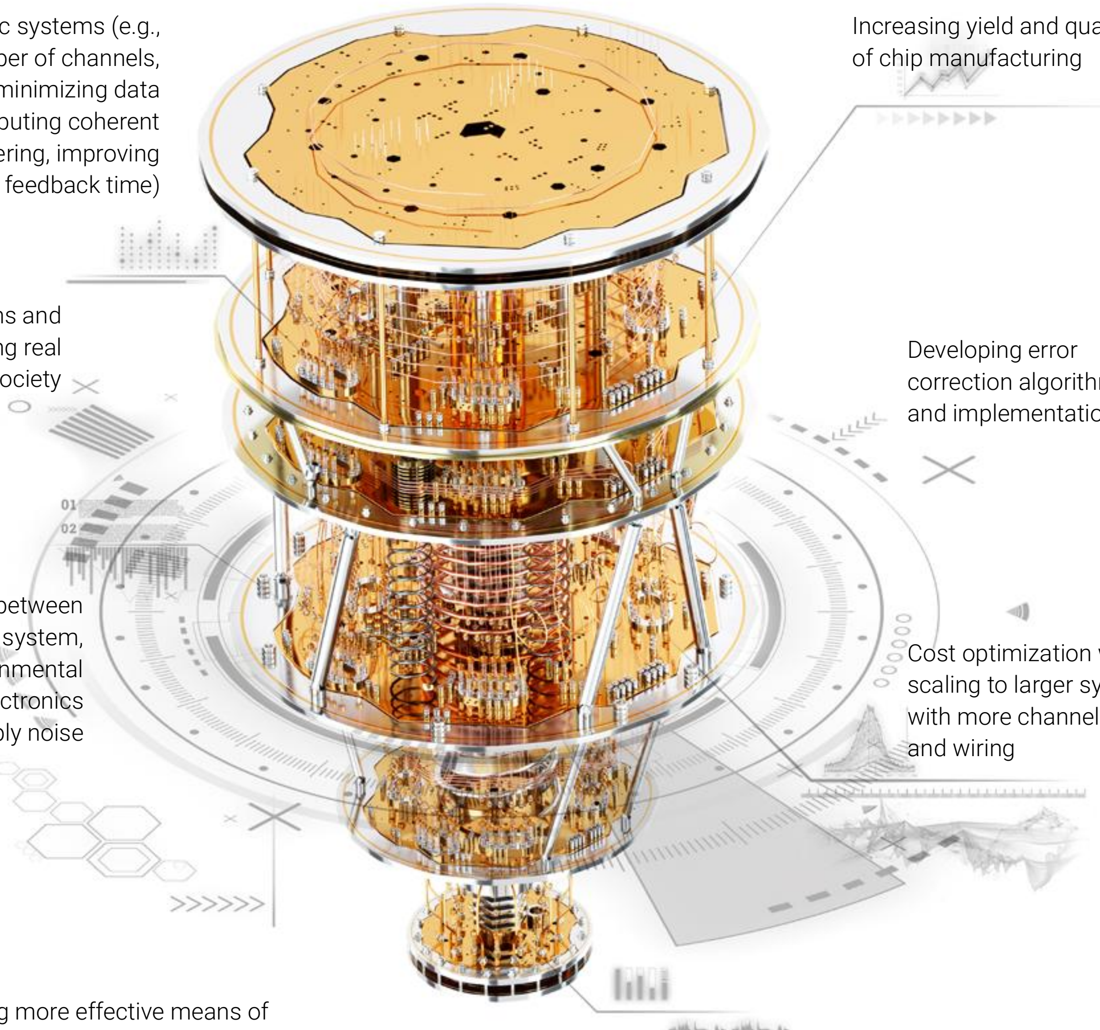
Down the Road for QUANTUM TECHNOLOGIES

Today, quantum computing is in the NISQ era, where engineering teams are actively coping with intrinsic noise in their quantum computing systems. Algorithms are designed to manage intrinsic noise and chip topologies are optimized for specific applications. Some companies are introducing other computational elements, like linear resonators, to mediate certain coupling effects. Even those with “standard” quantum computing offerings need to, for example, adjust bit connections based on application requirements (e.g., noise, speed).

During the NISQ era, error mitigation requires clever means of running and defining application-specific computations and post-processing techniques to improve outputs. In about a decade, the industry will move into the next phase of quantum computing, quantum error correction (QEC). Today, there are small-scale proof of concepts for error correction implementations. In the QEC phase, the industry expects enough qubits to be able to apply redundancy techniques to eliminate computational errors. This may require very low latency feedback loops between the electronics that are writing and reading the state of a qubit, so corrections can be applied in near-real-time (i.e., in the order of 100 nanoseconds (ns) or less) to ensure correct readings.

Looking ahead

INDUSTRY PRIORITIES



Scaling electronic systems (e.g., increasing the number of channels, minimizing latency, minimizing data loading time, distributing coherent clocks and triggering, improving feedback time)

Identifying algorithms and applications that bring real value to society

Minimizing crosstalk between different parts of the system, shielding from environmental noise, isolating electronics from power supply noise

Determining more effective means of increasing analog performance in RF arbitrary waveform generators (AWGs) and RF readout electronics by minimizing noise (e.g., noise floor, phase noise, thermal noise)

Increasing yield and quality of chip manufacturing

Developing error correction algorithms and implementations

Cost optimization when scaling to larger systems with more channels and wiring

In quantum computing systems requiring a cryostat, decreasing the footprint for wiring and radio frequency (RF) signal conditioning components

Drawing on
MODULAR TECHNOLOGIES
for Quantum Computing Control Systems, Where Possible

At this point in the history of quantum computing systems, there have been some attempts at standardization in the software space, but not as many in terms of hardware. Modular open-standards platforms are extremely important in efforts to scale and may help define standards for capacity and power efficiency.

Modular hardware systems shorten development time and provide a solid expandable digital backend without succumbing to higher loading and set-up times or higher latency. These benefits, with minimal ancillary engineering effort, allow engineers to focus on the bigger technical challenges and application-specific requirements they are facing.

Challenges to Overcome When Building a **Quantum Computing Control System on a Modular Base**

CHALLENGE 1:

Quantum computing companies don't have the time to develop a fully custom control system with their own custom backplanes and protocols, but they still need effective options to improve timing, data loading, and feedback latencies.

EXAMPLE: PCIe / PXI systems and backplanes can be used to build modular, scalable electronics control systems. However, many of the native functionalities do not meet the performance requirements for quantum computing control. Quantum computing companies develop their own solutions for certain functionalities that are already supported by the protocols. For example, if the synchronization clocks aren't fast enough, engineering teams can create their own protocol for modular boards.

CHALLENGE 2:

Modular platforms aren't scaling at the same rate as quantum computers.

EXAMPLE: The PCIe protocols currently in use accommodate 256 PCIe buses. In modular PXI control systems, each board/slot needs one bus, and the CPU card and the PCIe switches occupy buses. This limits the number of parallel channels and ultimately limits the industry to 20 to 54 qubits. While information transfer latency must be considered, it is possible to scale by synchronizing 256 endpoints in a PCIe tree and synchronizing several PCIe trees together or implementing functions into PCIe switches to allow a much higher number of buses. However, solutions like this add communication latency that must be considered.

CHALLENGE 3:

Quantum computing companies need faster synchronization clocks and expanded endpoints in standard protocols. The goal is to control more endpoints and, by extension, provide feedback between more endpoints.

EXAMPLE: PXIe protocol uses 10 and 100 MHz synchronization clocks. If a quantum computing company uses external ports and a synchronization of 1 GHz between different models, 10 MHz does not support synchronization on the nanosecond scale. For control electronics, cooling needs to be dimensioned to the amount of power since EMC noise can come from the environment, power supplies, and the board.

Finding the RIGHT PARTNER

Even considering these challenges, engineers move forward faster with modular building blocks, including open-standards hardware platforms and standard system architecture, than starting from scratch with time-consuming custom infrastructure. These systems also make it easier to scale from an initial prototype to high-volume production for those who are still in the early stages of design.

When development challenges inevitably appear, it is important to have a partner who can help determine chassis-level solutions that move the engineering team closer to desired specifications. Further, ensure you have access to support when customizations are warranted to meet industry standards.

nVent SCHROFF understands the challenging tradeoffs in quantum computing control systems, and we can help engineers:

- Evaluate tradeoffs
- Better select hardware to serve as a strong, scalable foundation
- Reduce supply chain complexity and adapt to changing requirements with one provider, ensuring streamlined access to: cabinets, cooling solutions, cable management, front panels, mechanical housing, and power distribution

For more information on modular, open platforms as a foundation for scalable quantum computing control systems CONTACT US.

Authors

Jorge Santos, PhD

Jorge Santos studied physics and bioengineering at the University of Lisbon, Portugal. Later, he went on to achieve a doctoral degree in quantum physics at the University of Aalto, Finland.

He has professional experience in several industries, including oil and gas, electronics design, and financial services. In 2019, he joined IQM Quantum Computers as one of the first employees. At IQM, he worked as an RF engineer, developing the electronics control systems for quantum computers. He went on to grow IQM's capabilities as a product development manager and, later, as a product manager responsible for IQM's on-premise hardware and software solutions. Today, he supports IQM's strategy and corporate development.

Christian Ganninger

Christian Ganninger studied electrical engineering at the University of Applied Science in Karlsruhe, Germany. He went on to work as a design engineer, technical coordinator, and project manager focused on 19" systems and backplanes.

In 2005, he joined nVent SCHROFF as a product manager. In that role, he focused on backplanes, MicroTCA, and power supplies. After a stint in category and product management from 2011 to 2014, he took on his current role as a Global Product Manager in the systems division of nVent SCHROFF.

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