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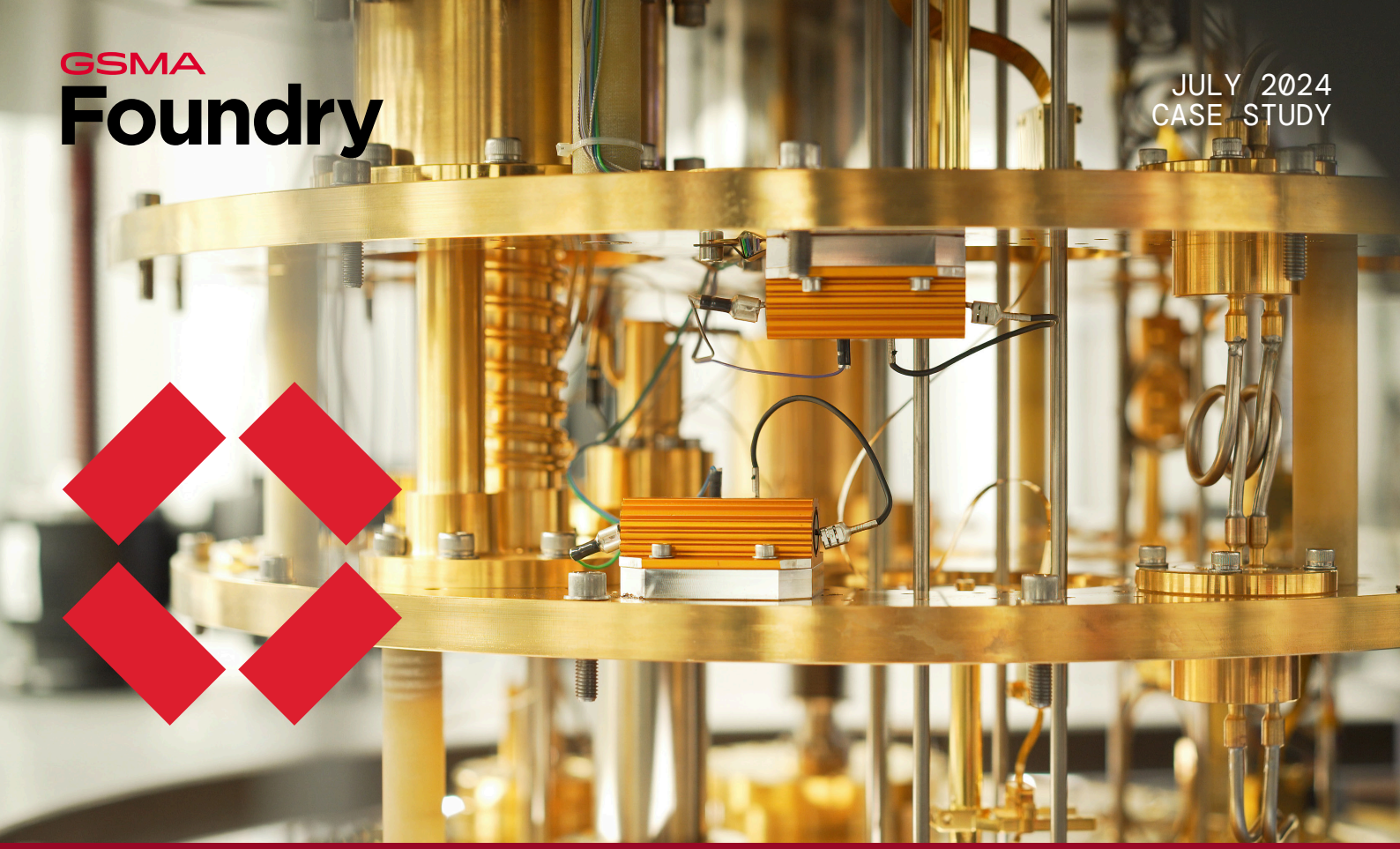
CASE STUDY



Quantum Computing: **Thinking Differently**

By going analogue, Qilimanjaro is hoping to pave the way to a new computer paradigm

Executive Summary

Computer scientists are trying to harness the laws of quantum mechanics to develop a new computing paradigm that can both solve intractable problems and process large amounts of data far more efficiently than classical computing. But with digital quantum computing facing significant technical challenges, some experts are exploring an alternative way forward.

Barcelona-based Qilimanjaro, for example, is developing an analogue QASIC (quantum application-specific integrated circuit) architecture. Its "full-stack" quantum computers, encompassing the chip, the accompanying software, the operating system and the access layers, are designed to address complex problems across the economy and applied sciences, as well as dramatically lowering the energy costs of training the neural networks that underpin AI. Qilimanjaro says its prototypes have a longer coherence time - the period that the system will behave in a quantum manner – than that of competitors. It is now focusing on scaling its superconducting qubits hardware.

By early 2025, Qilimanjaro intends to start offering "quantum-as-a-service" (QaaS) – access through the cloud to quantum computing systems, as well as co-designed chips and algorithms tailored to the needs of various industries.

As it seeks to grow, the five-year-old start-up is securing seed funding and preparing for a Series A funding round in 2025. Qilimanjaro is also generating revenues from initial commercial engagements, enabling it to strengthen its development, engineering, business and marketing teams, and speed up chip prototyping and production.

To help solve some of the world's most pressing challenges, such as climate change and the rising cost of healthcare, we need more capable computers. But the decades-long progress in chip miniaturisation that has underpinned the ongoing advances in classical computing is petering out.

"We cannot keep creating smaller more powerful chips, because we are starting to see quantum effects that are perceived as uncontrollable noise," explains Marta Estarellas, CEO of Qilimanjaro, a quantum computing company, founded in Barcelona in 2019. "The alternative now is to make computers larger. Supercomputers and large data centres nevertheless have their own limitations in terms of size, cost and sustainability (taking the power equivalent of 80,000 households). This is not a scalable approach and a new computing paradigm is required."

Employing the laws of quantum mechanics to encode and manipulate information, quantum computing is widely seen as the most promising new paradigm. As well as being far more energy efficient[1], Qilimanjaro and other proponents contend that quantum computing is better suited to tackling challenges that involve an intimate understanding of the natural world. "There are very complex systems that are difficult to simulate because the mathematical description that they have is intrinsically quantum and classical computers are not able to express this complexity," explains Marta Estarellas. "And this is very important because if we want to keep advancing and understand the nature that surrounds us, with the implications this knowledge has for applied technologies, we need to have more capacity to simulate these systems to develop new medicines, new materials, new fuels and better understand the universe."

Removing gates, reducing errors

While most of its peers are developing digital quantum computing, Qilimanjaro is taking a different approach using an analogue QASIC (quantum application-specific integrated circuit) architecture. Digital quantum computers encode algorithms into a sequence of gates, known as a quantum circuit, which is very similar to how classical computers work, explains Marta Estarellas "Unfortunately, these systems are very sensitive to errors and fluctuations from the environment," she adds. "On top of that, every time we apply a gate, we are introducing additional errors. The limitation that we find with commercially-available digital solutions is that the errors are too high to make any practical use of the computation."

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[1] Google's Quantum Supremacy paper, published in 2019, indicated that in some scenarios quantum processing would consume seven orders of magnitude less energy than a classical approach.

To correct such errors, very large quantum chips will be required. "At the moment, we are dealing with chips of the order of 100 qubits and we will need millions of qubits to be able to have error correction protocols implemented," Marta Estarellas contends. "So we are still far away from this in terms of size of the hardware." Qilimanjaro believes it will be at least 15 years before the digital approach has matured to a point where it can be applied extensively to real world problems.

In the meantime, before error correction is available, Qilimanjaro says analogue quantum computing can provide a robust alternative that has the potential to solve various practical problems, such as the simulation of intrinsically quantum problems in chemistry, physics or materials, optimisation of complex industrial problems and efficient training of artificial intelligence (AI) systems. Whereas a digital quantum computer slices problems into a set of discrete operations, analogue quantum computers encode the problem in the quantum description of the device and let the system evolve with time under continuous control. The idea is to bypass the need for heavy error correction protocols and their associated qubit overheads.

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"You are not introducing the additional errors coming from the fast operations that involve the application of each logical gate, but manipulate the system's parameters in a continuous and more robust manner," explains Marta Estarellas. "And nature is not digital, nature is analogue, so if you want an accurate description of a continuous process, such as a chemical reaction you better use an analogue quantum computer. If you try to digitise it into discrete operations, you are introducing errors and that's what we are seeing with digital computers."

Proving quantum advantage

However, analogue quantum computing is still quite nascent. As it has not been the subject of as much R&D as its digital counterpart, the analogue approach is at a relatively early stage in its development. In particular, Qilimanjaro still needs to prove, as with other quantum computing providers, that its analogue QASIC technology can deliver "quantum advantage" – a demonstration that a quantum computer can address a given problem of economic value, faster, more accurately or with less resources than a classical computer.

"I think we will see this soon," predicts Marta Estarellas. "The way we try to maximise the chances of finding this quantum advantage is, instead of having general purpose systems that are universal that you can program everything and tune all the parameters, is having something more dedicated to a specific use case."

To that end, Qilimanjaro is developing "full-stack" quantum computers, encompassing the chip, the accompanying software, the operating system and the access layers that allow users to interact with the system. Like Google and IBM, it is employing superconducting qubits as its preferred quantum computing hardware, but with a differentiated architecture.

A key performance indicator for these systems is coherence time - the time that the system will behave in a quantum manner. “If your coherence time is shorter than your algorithm then, once your coherence time is finished, your algorithm is running on a system that does not behave in a quantum manner,” explains Marta Estarellas. Therefore, Qilimanjaro’s initial objective was to ensure that its prototypes have longer coherence times than alternative systems. Through experimentation with different chip geometries and different components, “we already managed some outstanding coherence times from the very early prototypes,” says Marta Estarellas. “Our designs have very long coherence times, but we still want to keep improving.”

The next step is to scale the chips Qilimanjaro is using. The more qubits and more units of coding, the more complex algorithms you can solve. As well as addressing optimisation problems across the economy, including in the telecoms sector, Qilimanjaro is aiming to develop a quantum system that can dramatically lower the energy costs of training the neural networks that underpin AI and simulate quantum problems.

Deploying quantum systems for developers

As it seeks to generate revenues, Qilimanjaro is beginning to deliver prototype quantum computers to high performance computing centres and other facilities. For example, it has helped to deploy a digital quantum computer in the UAE, providing expertise and consulting support to the local team in Abu Dhabi. It has also supplied a quantum computer to the Barcelona Supercomputing Centre through the Quantum Spain project and is expects to address similar opportunities elsewhere.

Although the performance of these prototypes does not yet surpass that of a classical supercomputer, policymakers are keen to give citizens early access to what could be one of the key strategic technologies of the future. “They are looking to democratise technology to ensure that this is available for the end user,” explains Marta Estarellas. “You can start understanding how to programme it, start understanding how the algorithms are built and start thinking, what are the applications? This is an amazing initiative at the European level because it’s the first steps to move the technology from the lab to the industry.”

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With geopolitical tensions rising, national governments and regional groups, such as the EU, are also keen to be as self-sufficient as possible with key technologies. The potential for disruption to global supply chains means neither business leaders nor policymakers want to be too dependent on distant third countries for key technologies, such as computer chips.

By the end of 2024 or early in 2025, Qilimanjaro is planning to begin offering “quantum-as-a-service” (QaaS) – access through the cloud to quantum computing systems, as well as co-designed chips and algorithms tailored to the needs of various industries. “I want a facility where the client can connect remotely online through what we call a quantum-as-a-service solution where they have access to the latest setups that we develop with the latest software, latest chips, selected applications

and so on," explains Marta Estarellas. "And they don't have to make a million investment in buying the computer, they pay by use or a subscription and we think this is the more scalable business model for our clients."

Telecoms operators could ultimately play a major role in enabling end-users to access quantum computing. "Once quantum computers are out there, it will be very important to connect them," notes Marta Estarellas. "And the connectivity and the infrastructure that you need to connect to quantum computers is not the same as the one that we have now. So, it's important for [telcos] to be on top of this technology because it will indeed have an impact on communications as well."

Combining R&D with commercialisation

As of May 2024, Qilimanjaro had 45 full-time employees, of which it considers 85% to be leading experts in quantum computing technologies. As it grows, Qilimanjaro is trying to get the right balance between developing its core technology in the lab and doing practical work with clients that will give it insights into how quantum computing will be applied in the real world. Its quantum-as-a-service proposition will be open to beta testers that will provide Qilimanjaro with valuable feedback.

It is also working with several companies that are interested in applying quantum computing to optimisation problems. "We make sure that they are well aware that that they will likely need to have large complex quantum chips that are not available yet, but they are still interested because they want to have a foot in the door for once the hardware is ready," says Marta Estarellas.

Having initially bootstrapped Qilimanjaro, the founders are now closing a seed funding round and are preparing for a Series A funding round in early 2025. The goal is to strengthen the development, engineering, business and marketing teams, as well as incorporating a full-equipped prototyping lab to ensure faster chip prototyping and production, and become technologically self sufficient.

While recognising that quantum computing is still a very nascent technology, Marta Estarellas stresses the need to be investing now, given the long lead times that will be required to build up the expertise and capabilities in both chips and software. "We want to make sure that this technology ends up being completely democratised, that everybody has access to it, that everybody has the capacity to build on top of it, because it's something that really needs to be developed in a collaborative manner to have a revolutionary impact," she concludes.

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About the GSMA

The GSMA is a global organisation unifying the mobile ecosystem to discover, develop and deliver innovation foundational to positive business environments and societal change. Our vision is to unlock the full power of connectivity so that people, industry, and society thrive. Representing mobile operators and organisations across the mobile ecosystem and adjacent industries, the GSMA delivers for its members across three broad pillars: Connectivity for Good, Industry Services and Solutions, and Outreach. This activity includes advancing policy, tackling today's biggest societal challenges, underpinning the technology and interoperability that make mobile work, and providing the world's largest platform to convene the mobile ecosystem at the MWC and M360 series of events.

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The GSMA Foundry is the go-to place for cross-industry collaboration and making positive change happen, supported by leading technology organisations and companies. By bringing together members and key industry players, engaging, and unifying the end-to-end connectivity ecosystem, the GSMA is solving real-world industry challenges.

Our vision is to unlock the full power of connectivity so that people, industry, and society thrive. This enables the mobile industry's mission: to connect everyone and everything to a better future.

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About Qilimanjaro

Qilimanjaro is a full-stack quantum computing company based in Barcelona and founded in 2019 that aims at maximizing current technology capabilities to provide practical quantum advantage in a shorter time frame by following a unique strategy.

We use the analog model of quantum computation, with high-quality superconducting flux qubits and versatile qubit-qubit interactions to build app-specific quantum devices (QASIC), in a co-design approach that brings the design of the quantum chip closer to the use-case.

We develop tailored quantum computing solutions with a specific focus on simulation of hard physical and chemical problems, improvement of AI training and optimization. We enable our clients via an exclusive Quantum as a Service (QaaS) that allows for remote access to our distinctive quantum computing platforms and a boutique service for deployment and integration of in-premises quantum computers.

Among its achievements, Qilimanjaro has been responsible for delivering the first quantum computer in Spain, and expects to release its core QaaS product at the end of 2024.

About this case study