Physicists achieve fully optical readout of superconducting qubits

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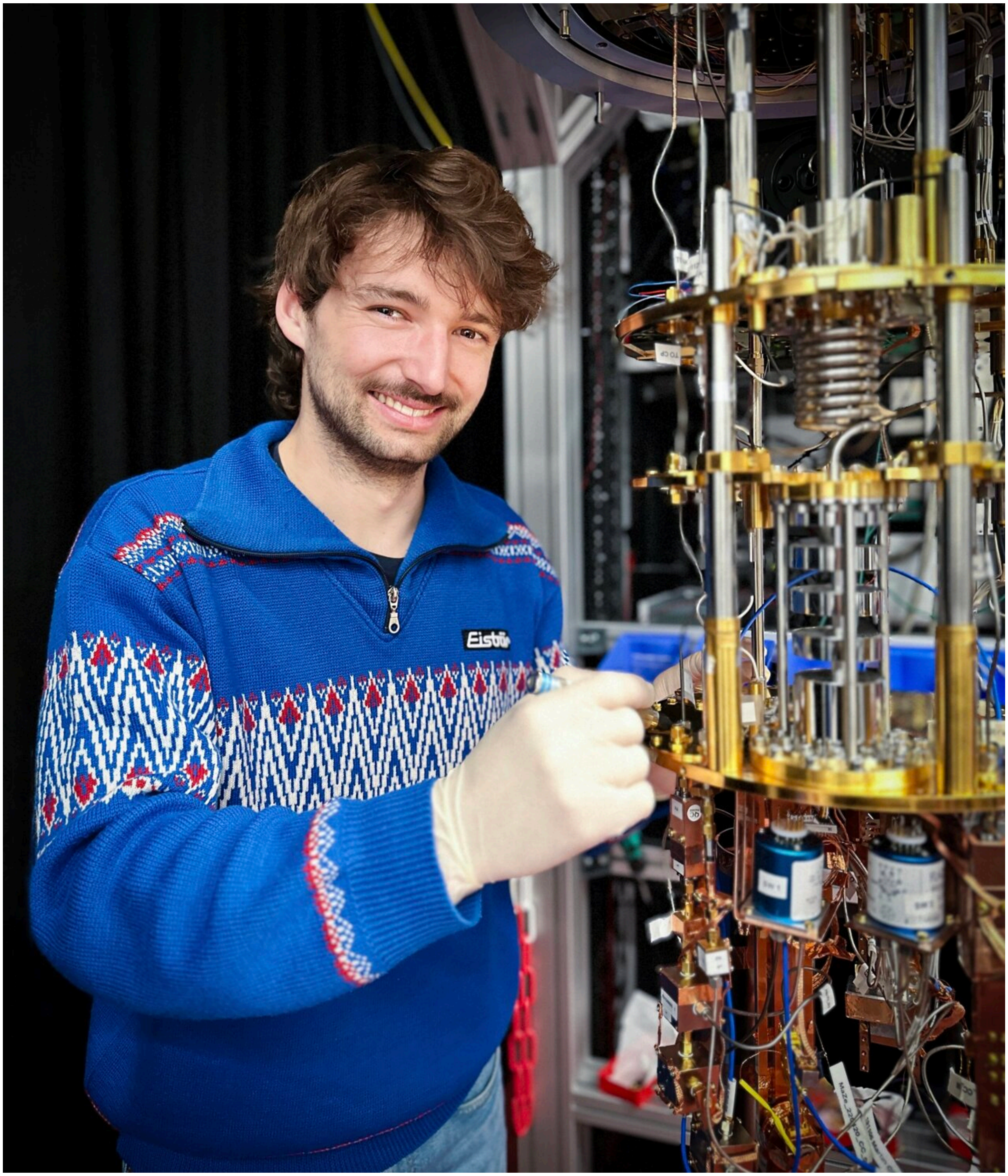


A team of physicists at the Institute of Science and Technology Austria (ISTA) achieved a fully optical readout of superconducting qubits, here co-first author Thomas Werner. Credit: ISTA

Qubits—the fundamental units of quantum information—drive entire tech sectors. Among them, superconducting qubits could be instrumental in building a large-scale quantum computer, but they rely on electrical signals and are difficult to scale.

In a breakthrough, a team of physicists at the Institute of Science and Technology Austria (ISTA) has achieved a fully optical readout of superconducting qubits, pushing the technology beyond its current limitations. Their findings are published in *Nature Physics*.

Following a year-long rally, quantum computing stocks were brought to a standstill barely a few days into the International Year of Quantum Science and Technology. The reason for this sudden setback was Nvidia CEO Jensen Huang's keynote at the CES 2025 tech trade show, where he predicted that "very useful quantum computers" were still two decades down the road.

Aside from stock markets and tech trade shows, the race continues fiercely toward scalable quantum computers that could perform some calculations exponentially faster than "classical" computers. While this promising "quantum advantage" resulted in the rapid development of quantum hardware, many technical hurdles must still be overcome before quantum computers become "useful."

Now, a team of physicists from Professor Johannes Fink's group at the Institute of Science and Technology Austria (ISTA) has managed to overcome an important limitation, which could help scale up quantum computers. By ensuring the qubits understand the language of fiber optics, the team considerably reduced the amount of cryogenic hardware needed to measure them.

"This new approach might allow us to increase the number of qubits so they become useful for computation. It also lays the foundation for building a network of superconducting quantum computers connected via optical fibers at room temperature," says co-first author Georg Arnold, a former Ph.D. student in the Fink group at ISTA.

The challenges of applying fiberoptics to superconducting quantum hardware

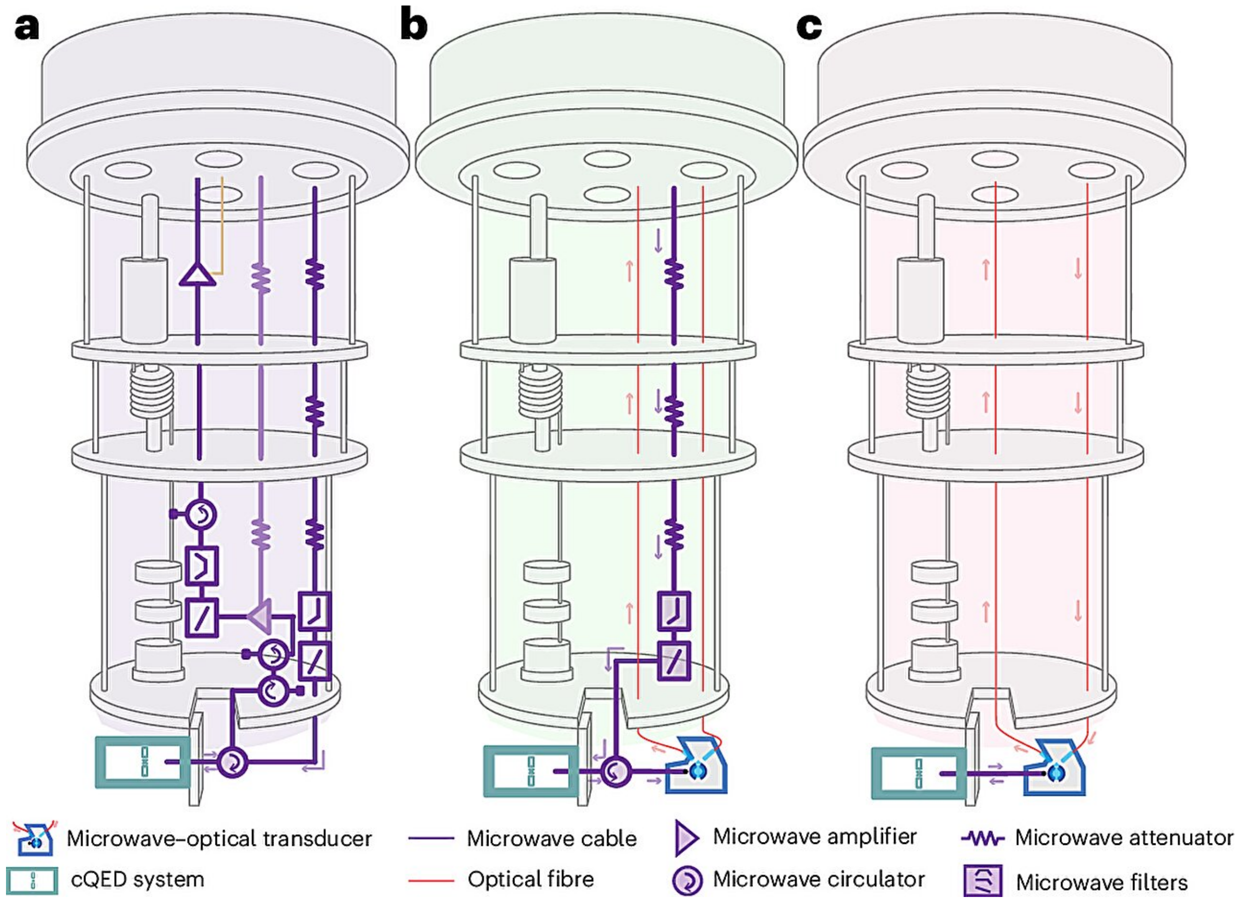
While fiberoptics have revolutionized the telecom industry with their multiple advantages over electrical transmission and enabled high-speed communication, applying optics to quantum hardware is no easy task. Superconducting quantum computers, which use special physical properties of materials at temperatures near absolute zero, present a challenge of their own.

To realize superconducting qubits, tiny electrical circuits are cooled to extremely low temperatures where they lose all electrical resistance and can thus maintain a flowing current indefinitely.

"Thus, superconducting qubits are electrical by definition. To make them, we must reach temperatures of only a few thousandths of a degree above absolute zero. That's even colder than space," says Arnold.

However, electrical signals have a comparably low bandwidth, meaning they transmit little information per unit of time. Easily overwhelmed by noise, they are also prone to information loss. Also, the required wiring dissipates lots of heat. Thus, the "qubit readout," i.e., detecting and measuring qubits by sending an electric signal that they reflect, requires colossal cryogenic cooling as well as elaborate and expensive electrical components for filtering and amplification.

On the other hand, higher-energy optical signals—for example, at telecom wavelengths—propagate in thin optical fibers with minuscule losses. In addition, they have a considerably lower heat dissipation and much higher bandwidth. So, using them to push the limits of superconducting quantum hardware would be ideal, if only the qubits would understand their language.



Comparison of conventional and optical qubit readout set-ups in a dilution refrigerator. Credit: *Nature Physics* (2025). DOI: 10.1038/s41567-024-02741-4

'Translating' the optical signal to the qubits

To achieve a fully optical readout in superconducting quantum hardware, the team needed to find a way to 'translate' the optical signal to the qubits and back.

"Ideally, one would try to get rid of all electrical signals, as the required wiring transports a lot of heat into the cooling chambers where the qubits are. But this is not possible," says co-first author Thomas Werner, a Ph.D. student in the Fink group at ISTA.

So, the researchers thought of using an electro-optic transducer to convert the optical signal to a microwave frequency—an electrical signal that the qubits can understand. In response, the qubits reflect a microwave signal that the transducer converts to optics.

Werner highlights the delicacy of the task, "We showed that we can send infrared light close to the qubits without making them lose their superconductivity." Using the electro-optic transducer as a switch allowed the team to connect the qubits directly to the outside world.

Overcoming the qubit barrier and other advantages

To do 'useful' computation with quantum computers, thousands or even millions of qubits are necessary. However, the infrastructure has difficulty keeping up because the cryogenic cooling requirements to detect and measure them are prohibitive.

"Our technology can decrease the heat load of measuring superconductive qubits considerably. This will allow us to break the qubit barrier and scale up the number of qubits that can be used in quantum computing," says Arnold.

Achieving a fully optical readout of superconducting qubits also allowed the researchers to rid the setup of many of its cumbersome electrical components. The electrical signal in conventional readout systems is highly error-prone, requiring large-scale signal correction using many technically limiting and expensive electrical components that must also be cooled to cryogenic temperatures.

"So, by using the electro-optic transducer to disconnect the qubits from the electrical infrastructure, we were able to replace all the remaining parts of the setup with optics," says Werner. This makes the system not only more robust and efficient, but also reduces its costs.

Interfacing superconducting quantum computers via room-temperature links

This technology could help increase the number of usable superconducting qubits even further by allowing scientists to interface multiple quantum computers using light. Currently, quantum computers need so-called "dilution refrigerators" to provide cooling for the entire measurement setup, including any required connections between processor modules.

"But these dilution refrigerators also have practical limitations and can't be made infinitely large," says Arnold. In turn, the space and cooling restrictions limit the number of usable qubits. But now, connecting two qubits in two separate dilution refrigerators using an optical fiber might be within reach, according to the researchers.

"The infrastructure is available, and now we have the technology that allows us to build the first simple quantum computing networks," says Arnold.

The ISTA physicists have reached a significant milestone in developing superconducting quantum hardware, but much more remains to be done.

"The performance of our prototype is still quite limited—in particular with regard to the amount of optical power needed and dissipated. Nevertheless, it serves as a proof of principle that a fully optical readout of superconducting qubits is even possible. It will be the industry's role to push the technique further."

More information: Georg Arnold et al, All-optical superconducting qubit readout, *Nature Physics* (2025). DOI: 10.1038/s41567-024-02741-4

Provided by Institute of Science and Technology Austria

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