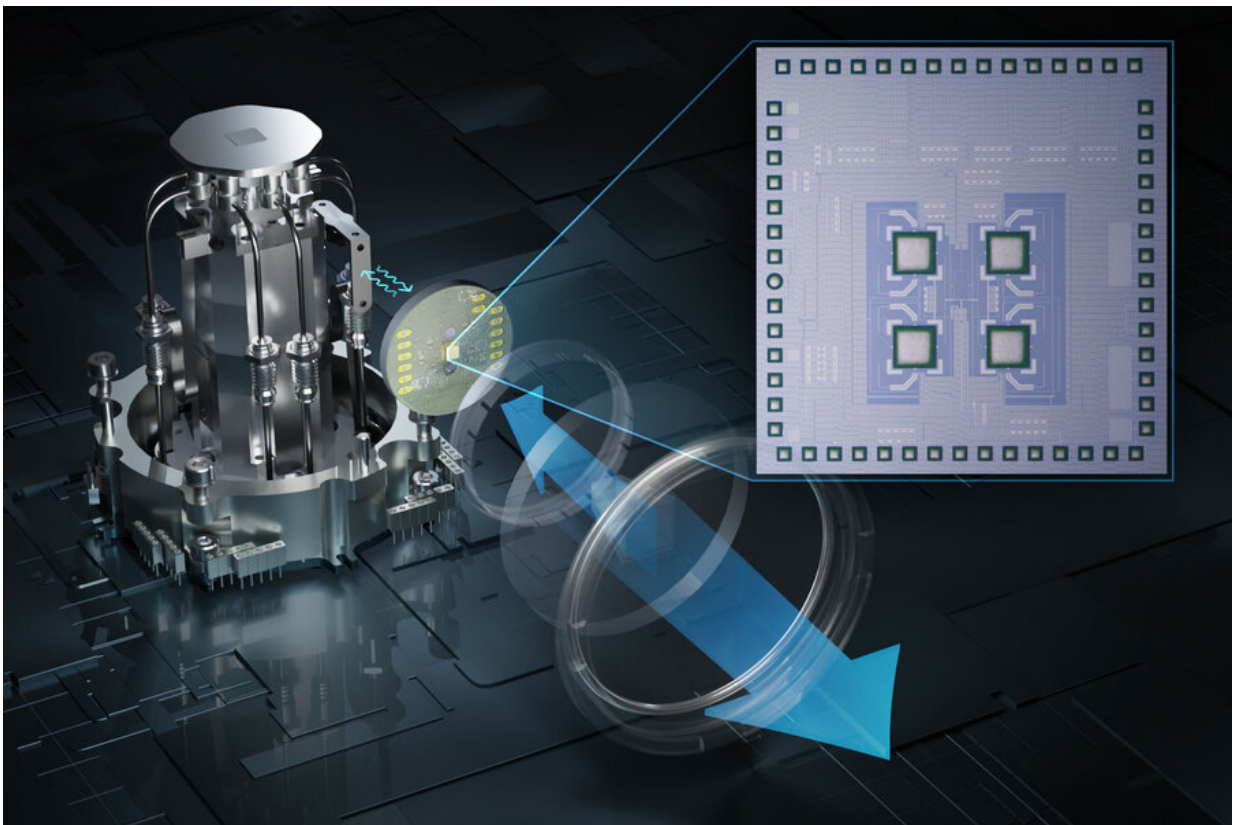


Wireless technique enables quantum computer to send and receive data without generating too much error-causing heat

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This image shows a transceiver chip the researchers developed that is placed inside a complex refrigerator that houses a quantum computer. The chip sends and receives data to and from electronics outside of the refrigerator using high-speed terahertz waves. Credit: Jinchun Wang

Heat causes errors in the qubits that are the building blocks of a quantum computer, so quantum systems are typically kept inside refrigerators that keep the temperature just above absolute zero (-459 degrees Fahrenheit).

But quantum computers need to communicate with electronics outside the refrigerator, in a room-temperature environment. The metal cables that connect these electronics bring heat into the refrigerator, which has to work even harder and draw extra power to keep the system cold. Plus, more qubits require more cables, so the size of a quantum system is limited by how much heat the fridge can remove.

To overcome this challenge, an interdisciplinary team of MIT researchers has developed a [wireless communication system](#) that enables a quantum computer to send and receive data to and from electronics outside the refrigerator using high-speed [terahertz waves](#).

A transceiver [chip](#) placed inside the fridge can receive and transmit data. Terahertz waves generated outside the refrigerator are beamed in through a glass window. Data encoded onto these waves can be received by the chip. That chip also acts as a mirror, delivering data from the qubits on the [terahertz](#) waves it reflects to their source.

This reflection process also bounces back much of the power sent into the fridge, so the process generates only a minimal amount of heat. The contactless communication system consumes up to 10 times less power than systems with metal cables.

"By having this reflection mode, you really save the power consumption inside the fridge and leave all those dirty jobs on the outside. While this is still just a preliminary prototype and we have some room to improve, even at this point, we have shown [low power consumption](#) inside the fridge that is already better than metallic cables. I believe this could be a way to build largescale [quantum systems](#)," says senior author Ruonan

Han, an associate professor in the Department of Electrical Engineering and Computer Sciences (EECS) who leads the Terahertz Integrated Electronics Group.

Han and his team, with expertise in terahertz waves and [electronic devices](#), joined forces with associate professor Dirk Englund and the Quantum Photonics Laboratory team, who provided quantum engineering expertise and joined in conducting the cryogenic experiments.

Joining Han and Englund on the paper are first author and EECS graduate student Jinchun Wang; Mohamed Ibrahim Ph.D. '21; Isaac Harris, a graduate student in the Quantum Photonics Laboratory; Nathan M. Monroe Ph.D. '22; Wasiq Khan Ph.D. '22; and Xiang Yi, a former postdoc who is now a professor at the South China University of Technology. The paper will be presented at the [International Solid-Sates Circuits Conference](#).

Tiny mirrors

The researchers' square transceiver chip, measuring about 2 millimeters on each side, is placed on a quantum computer inside the refrigerator, which is called a cryostat because it maintains cryogenic temperatures. These super-cold temperatures don't damage the chip; in fact, they enable it to run more efficiently than it would at room temperature.

The chip sends and receives data from a terahertz wave source outside the cryostat using a passive communication process known as backscatter, which involves reflections. An array of antennas on top of the chip, each of which is only about 200 micrometers in size, act as tiny mirrors. These mirrors can be "turned on" to reflect waves or "turned off."

The terahertz wave generation source encodes data onto the waves it sends into the cryostat, and the antennas in their "off" state can receive those waves and the data they carry.

When the tiny mirrors are turned on, they can be set so they either reflect a wave in its current form or invert its phase before bouncing it back. If the reflected wave has the same phase, that represents a 0, but if the phase is inverted, that represents a 1. Electronics outside the cryostat can interpret those binary signals to decode the data.

"This backscatter technology is not new. For instance, RFIDs are based on backscatter communication. We borrow that idea and bring it into this very unique scenario, and I think this leads to a good combination of all these technologies," Han says.

Terahertz advantages

The data are transmitted using high-speed terahertz waves, which are located on the electromagnetic spectrum between radio waves and infrared light.

Because terahertz waves are much smaller than radio waves, the chip and its antennas can be smaller, too, which would make the device easier to manufacture at scale. Terahertz waves also have higher frequencies than [radio waves](#), so they can transmit data much faster and move larger amounts of information.

But because terahertz waves have lower frequencies than the light waves used in photonic systems, the terahertz waves carry less quantum noise, which leads to less interference with quantum processors.

Importantly, the transceiver chip and terahertz link can be fully constructed with standard fabrication processes on a CMOS chip, so they

can be integrated into many current systems and techniques.

"CMOS compatibility is important. For example, one terahertz link could deliver a large amount of data and feed it to another cryo-CMOS controller, which can split the signal to control multiple qubits simultaneously, so we can reduce the quantity of RF cables dramatically. This is very promising," Wang says.

The researchers were able to transmit data at 4 gigabits per second with their prototype, but Han says the sky is nearly the limit when it comes to boosting that speed. The downlink of the contactless system posed about 10 times less heat load than a system with metallic cables, and the temperature of the cryostat fluctuated up to a few millidegrees during experiments.

Now that the researchers have demonstrated this wireless technology, they want to improve the system's speed and efficiency using special terahertz fibers, which are only a few hundred micrometers wide. Han's group has shown that these plastic wires can transmit data at a rate of 100 gigabits per second and have much better thermal insulation than fatter, metal cables.

The researchers also want to refine the design of their transceiver to improve scalability and continue boosting its energy efficiency. Generating terahertz waves requires a lot of power, but Han's group is studying more efficient methods that utilize low-cost chips. Incorporating this technology into the system could make the device more cost-effective.

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