The first observation of time-domain oscillations between two distant semiconductor spin qubits

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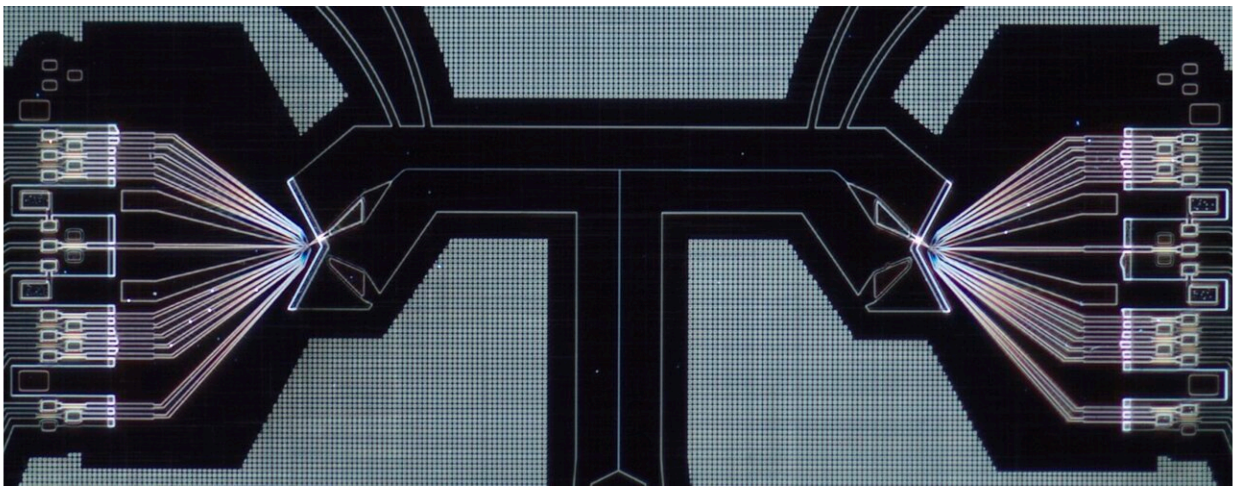


Dark-field microscope image showing the superconducting resonator (thin bright horizontal line) coupled to two gate-defined double dots. The gate fan-out of the respective dots is visible to the left and right of the resonator. The device is measured by recording the microwave transmission from the input port (top left) via the resonator to the output port (top right). Credit: TU Delft/QuTech, Vandersypen lab.

Quantum computing holds the promise of outperforming classical computing on some optimization and data processing tasks. The creation of highly performing large-scale quantum computers, however, relies on the ability to support controlled interactions between qubits, which are the units of information in quantum computing, at a range of distances.

So far, maintaining the coherence of interactions between distant semiconductor qubits, while also controlling these interactions, has proved challenging. By overcoming this hurdle, quantum physicists and engineers could develop more advanced quantum computers that can tackle more complex problems.

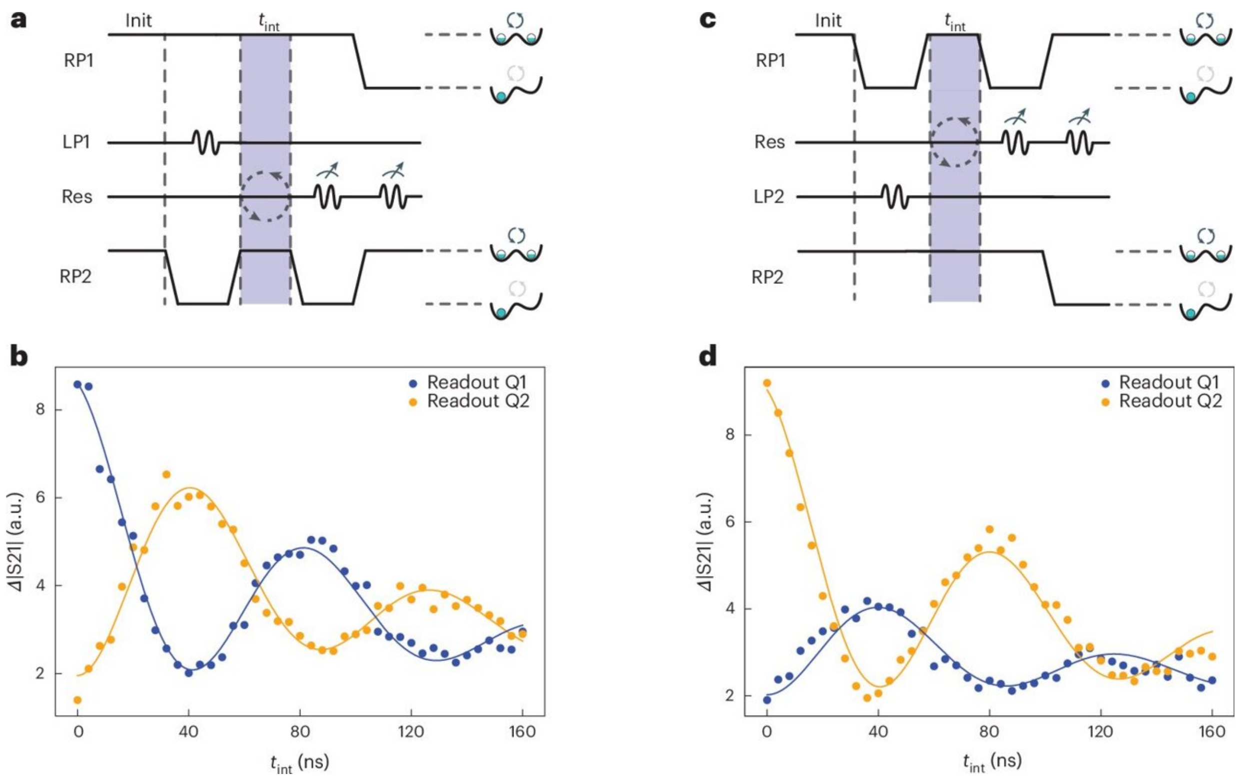
Researchers at Delft University of Technology (TU Delft) have devised a promising approach to realize coherent quantum interactions between distant semiconductor qubits. Their paper, published in *Nature Physics*, demonstrates the use of this approach to attain coherent interaction between two electron spin qubits that are 250 μm apart.

"Electron spins in semiconductor quantum dots are showing great promise for quantum information processing," Lieven Vandersypen, senior author of the paper, told Phys.org.

"However, scaling up architectures has been limited by the fact that the commonly used two-qubit-gate exchange interaction requires the spins to sit just 100 nm apart. Realizing two-qubit gates over much longer distances, say, beyond 10 microns, has been a long-standing goal in the community."

The study by Vandersypen and his colleagues builds on recent research efforts within the field of quantum computing. Specifically, it draws inspiration from the idea of scaling semiconductor spin qubit processors utilizing on-chip networks of coupled qubit registers.

These are networks that consist of several qubit modules integrated onto a single chip. Qubits in each of these modules collectively perform local quantum operations, while distant registers communicate with each other via long-range coupling mechanisms.



iSWAP oscillations between two distant spin qubits. Credit: *Nature Physics* (2024). DOI: 10.1038/s41567-024-02694-8

Inspired by this design, the researchers created a system with two semiconductor spin qubits that are 250 μm apart from each other. Using a superconducting resonator, they were able to demonstrate a coherent interaction between these two qubits.

"Each of the two spins in our system is confined in an electrostatically defined double quantum dot, 250 μm apart on the same chip," explained Vandersypen. "The spins interact indirectly, mediated by virtual photons in an on-chip superconducting resonator which is coupled to both double dots."

Vandersypen and his colleagues initialized one spin within their system in the ground state and the other in the excited state. When they activated the interaction between these spins, the two qubits could transfer their quantum states back and forth. When one spin transitions to the ground state, the other simultaneously transitions to the excited state, and vice versa.

"After several spectroscopic measurements relying on coherent spin-photon interactions in our group and elsewhere, now for the first time we observed time-domain oscillations," said Vandersypen. "Time-domain control of qubit interactions forms the basis for quantum logic involving distant spins, and by extension of on-chip networks of spin qubit registers."

The findings of this study highlight the promise of using superconducting resonators to enable coherent interactions between distant spin qubits. Vandersypen and his colleagues hope that their proposed approach will aid the future development of scalable networks of on-chip spin qubits, which could in turn be used to create better-performing quantum computers.

"Having observed time-domain oscillations between two spins mediated by virtual photons, we next aim at studying time-domain oscillations between each of the spins and real photons in the resonator, in the form of vacuum Rabi oscillations," added Vandersypen. "Eventually, we hope to build networks of qubit registers."

More information: Jurgen Dijkema et al, Cavity-mediated iSWAP oscillations between distant spins, *Nature Physics* (2024). DOI: 10.1038/s41567-024-02694-8.