"QUBIT-DRIVER" – METHOD OF OPERATING A QUANTUM SYSTEM

A step closer to the Quantum Computer – a pioneering method for reading and resetting a superconducting quantum bit

Reference – Blais 2023-021

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Context

Quantum technologies operate qubits, the basic ingredients. The creation of quantum computers, quantum simulators, or quantum detectors requires the measurement of the state of the qubits that compose them. The performance of these quantum devices is strongly dependent on the speed and fidelity of the qubit measurement. This is particularly the case for error correction protocols, a key element of a quantum computer.

Superconducting qubits are the most prevalent type of qubits in the quantum technologies. These qubits are measured by resonators. Until now it has been difficult to measure them with high precision because of unwanted transitions induced by the resonators that are not well understood. This is one of the most important problems in the field and this invention improves upon the state of the art.

Description

This invention is a method to operate a quantum system. It specifies what electromagnetic signals should be sent to qubits and resonators. It does not require any changes to the hardware or software of today's superconducting-qubits quantum computers.

"QUBIT-DRIVER" is a pioneering method for reading and resetting a superconducting qubit. It has been developed by an international team of renowned researchers, marking a significant advancement in quantum readout. The invention is a collaboration between the Université de Sherbrooke in Canada and the École Normale Supérieure de Lyon (ENS) in France, as well as the Centre national de la recherche scientifique (CNRS) in France.

The method enables the measurement of superconducting qubits with great speed and fidelity. The measurement is done by a resonator coupled to the qubit which together form a set. One microwave port is dedicated to addressing the qubit, while another port is employed for addressing the resonator. The approach involves irradiating both ports simultaneously in a way that excites the resonator without affecting the qubit. The qubit can thus be controlled at the same time that the resonator is pre-loaded with many measurement photons in anticipation of the measurement. To initiate the measurement, one of the two irradiations is turned off, which allows us to benefit from the large electromagnetic field accumulated in the resonator to quickly read out the state of the qubit.

One of the key advantages of the invention is that it enables the use of measurement microwave fields of much greater amplitude than what is possible with the state of the art, which makes it possible to read qubits with record speed and fidelity. This is of paramount importance for any measurement-based feedback quantum protocol. In particular, this can greatly speed up measurement-based quantum error correction, where multiple rounds of qubit measurements are conducted in between any two logical quantum operations. The invention is extremely simple to use since it does not require any changes to current quantum devices, only an improved way of operating them.

Furthermore, the method presented in this invention holds applicability in various other quantum technologies platforms. Specifically, it can be employed whenever a qubit or atom is coupled to a resonator.

Applications

- The domain of application is quantum technologies. In the short-term, those using superconducting qubit devices,
- Quantum computing,

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- Quantum simulators and detectors,
- The method applies to other types of qubits interacting with a resonator.
- Market
    - The market for quantum computing is experiencing significant growth, expected to reach from US$866 million in 2023 to over US$4.4 billion by 2028, at a CAGR of 38.3%.
    - The superconducting qubit segment is projected to account for the largest share of the quantum computing market from US$479 million in 2023 to US$2.5 billion in 2028. The growth of this segment can be attributed to faster operations of quantum computers based on superconducting-qubits technology than the computers equipped with other technologies.

Advantages

- Almost every superconducting-qubits device existing today has the hardware requirements to employ this method; certainly, those for quantum computation.
- Improves the accuracy and speed of the measurement of information stored in a quantum device – Demonstrated.
- Improves the accuracy of logical operations on qubits – Demonstrated.
- Protects quantum states from some errors – Demonstrated.
- Prepares the quantum device in states that are resources for quantum computation, metrology, and communication – Demonstrated by numerical simulations.
- The invention can be deployed today in devices of any size, from just a few to hundreds of superconducting qubits.
- The method is not limited to improving measurement; it allows, among other things, to cancel unwanted phase accumulations (due to ac-Stark shift) and to improve certain logic operations.
- Not limited to superconducting qubits; applies to all types of qubits coupled to a resonator.
- The presently employed technique utilized by both academic research groups and industry for the readout of superconducting qubits is referred to as "dispersive measurement." This method, while in widespread use, is characterized by typical accuracies that fall below 99%. These accuracy levels are deemed insufficient to realize the ambitious goal of constructing a large-scale quantum computer – this invention improves on that approach.
- The response of the quantum community to this invention has been overwhelmingly positive. The simplicity and the power of the invention was immediately understood.
- A new more efficient approach, while remaining easy to use.

Keywords

- Superconducting qubit, transmon, circuit quantum electrodynamics, qubit readout.

Technology Readiness Level (TRL)

TRL 7

- The operation of the method has been experimentally demonstrated in a device with one superconducting qubit by the collaborators at ENS Lyon.
- The inventors are in the process of fine-tuning the method to maximize performance.
- Scientific papers with details and results are available here:
    - Cloaking a qubit in a cavity – https://arxiv.org/abs/2211.05758
    - Qubit readouts enabled by qubit cloaking – https://arxiv.org/abs/2305.00895
    - *Nature Communications* – Cloaking a qubit in a cavity – https://doi.org/10.1038/s41467-023-42060-5

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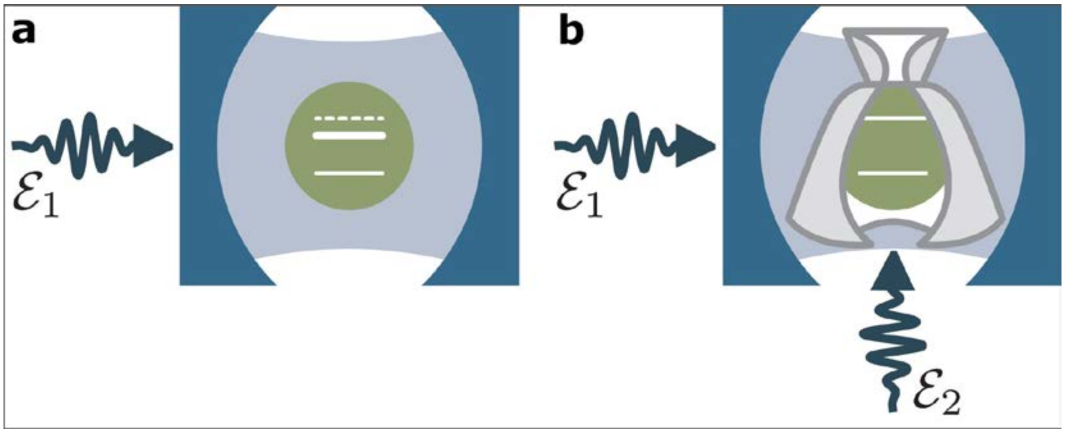

Illustration of the method – Figure adapted from Lledó, C., Dassonneville, R., Moulinas, A. *et al.* Cloaking a qubit in a cavity. *Nat Commun* **14**, 6313 (2023). https://doi.org/10.1038/s41467-023-42060-5.
In panel (a) we see a drive on the resonator accumulating electromagnetic field in its interior, which negatively affects the qubit by shifting its frequency and dephasing it. In panel (b) we see the resonator filled with the electromagnetic field but now the qubit is protected, illustrated by its surrounding cloak and its unshifted energy splitting. This is achieved by directly driving the qubit with a second electromagnetic signal with an amplitude, frequency, and phase prescribed by present method.

Intellectual Property

- International Patent application filed.
    - Being a fundamental invention, potential patent standardization is being studied.

Seeking

- Commercial partners
- Development partners
- Investments
- Licences

Companies of interest

- The approach could quickly be used by the majority of academic groups and companies working in the field with little or no modification to their experimental devices.
    - Essentially all companies working on superconducting qubits coupled with resonators could be interested.
    - Can be used to improve commercial quantum computers that exist today!
- IBM, Google, Intel, D-Wave Quantum Inc., Amazon, Microsoft, Rigetti Computing, IQM, Alice & Bob, Nord Quantique, others.

Research Team Leads

- Université de Sherbrooke – Professor Alexandre Blais is Scientific Director at the Institut Quantique of the Université de Sherbrooke and is a leader in the theoretical study of quantum superconducting circuits.
- École Normale Supérieure de Lyon – Professor Benjamin Huard leads the Quantum Circuit Group there and is an expert on superconducting circuits measurement and feedback.

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