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QUANTUM COMPUTING: TUNABLE INTERACTIONS FOR IMPLEMENTING TWO-QUBIT GATES AND SUPPRESSING SPURIOUS COUPLINGS VIA OFF-RESONANTLY DRIVEN COUPLER MODES IN A SUPERCONDUCTING CHIP

A step closer to the Quantum Computer – Extensible circuit-QED architecture via amplitude- and frequency-variable microwaves

Context

Quantum computing is set to change the way in which we solve complex and pressing problems. Several companies are currently working on this space, ranging from hardware providers such as IBM, Google and Amazon, to software providers such as Microsoft. Scaling up superconducting qubit technology to many qubits is possible but challenging. In fact, as no best or optimal solution to this problem is known to date, tradeoffs between architectural choices need to be considered. Not surprisingly, large corporations have taken different paths to scale up superconducting devices. Superconducting quantum circuits are a leading hardware architecture for building quantum computers. Engineering these processors involves designing the qubits, which are used to store and process quantum information, and methods for wiring two or more qubits to enable two-qubit gates.

Description

This invention is a collaboration between MIT in Boston and the Université de Sherbrooke in Canada. Our invention consists of a novel method to enhance and/or suppress multiqubit interactions by the application of off-resonant microwave drives to the coupler modes that connect the qubits. The solution constitutes a new possible platform for implementing high-fidelity operations in large arrays of qubits by exploiting a unit cell that integrates microwave-driven couplers. To engineer tunable multiqubit interactions by applying off-resonant drives to coupler modes for i) implementing quantum gates and ii) suppressing unwanted couplings in a superconducting quantum processor. Qubit connectivity can be realized by direct coupling or by a coupler mode. At the price of a larger hardware footprint, couplers can help increase the on-off ratio of the intended two-qubit coupling and mitigate issues related to qubit frequency crowding in large-scale chips.

Our method exploits the following effect: In the presence of an off-resonant microwave drive acting on the coupler mode, the “ZZ” interaction strength between the two qubits can reach tens to hundreds of MHz at certain drive frequencies and for typical qubit-coupler coupling strengths. Furthermore, such regimes of large ZZ interaction can be engineered by adjusting the parameters of the coupler and the qubits including their frequencies and anharmonicities in order to favor desired gate-operation conditions while avoiding spurious driving of qubit transitions.

Suppressing spurious interactions – A crucial benefit of our scheme is that the idling and driven properties of the system can be engineered independently. When the system idles and the drive is off, the system parameters, which become fixed after the fabrication of a chip, can be chosen such that spurious two-qubit interactions are conveniently reduced. Our scheme offers a second important advantage. Because spurious interactions that are always-on while the system idles cannot, in most cases, be completely suppressed, and because the sign and magnitude of the driven interaction strength is controlled by the parameters of the drive, a weaker drive on the coupler can be used to counteract the static unwanted interactions while the qubits idle.

Further technical details are available here:
- https://www.physique.usherbrooke.ca/blais/wp-content/uploads/2022/04/2204.08098.pdf

Applications

- The superconducting quantum processor for the quantum computer.
- 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%.
- Superconducting qubits occupy the first place by type of quantum processor and are estimated to reach $966 million by 2026.
- Targeted companies – IBM, Google, Amazon, Microsoft, others.

Advantages

- A coupler-based architecture with all-microwave interactions can result in substantial gains in gate fidelities and suppress the propagation of coherent (correlated) errors that are highly detrimental to quantum information processing.
- Extensibility – The methods described here can be directly ported to the multiqubit case.
- The described method is agnostic with respect to the qubit and coupler modality.
- Hardware-efficient solution for implementing fast and high-fidelity gates while being able to completely decouple these systems at their idling operating point.
- Because microwave drives can be tuned on and off on-demand, this method can enable fast CZ gates with potentially very high on-off ratios.
- Qubits can be operated at their optimal frequency for high coherence and be accommodated in a relatively large frequency band to alleviate issues related to frequency crowding.

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Keywords

- Two-qubit gate, two-qubit coupler, ZZ crosstalk suppression, CZ gate.

Technology Readiness Level (TRL)

- The Université de Sherbrooke performs the theoretical work and MIT tests the designed prototype devices in the lab. A theoretical-experimental cycle then ensues.
- TRL 3-4 – Several prototypes have been fabricated and tested.

Intellectual Property

- United States patent pending; publication imminent.

Seeking

- Commercial partners
- Development partners
- Investments
- Licences

Companies of interest

- Google, IBM, Amazon, Microsoft, others.

Research Team Leads

- Massachusetts Institute of Technology (MIT) – Professor William Oliver is the Director of the Center for Quantum Engineering at MIT. Pr. Oliver is a leader in the design, fabrication, and experimental measurement of superconducting qubits.
- 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.

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