QUANTUM COMPUTING: CANCELATION OF UNWANTED ZZ INTERACTIONS IN A SUPERCONDUCTING QUANTUM ARCHITECTURE OF ALTERNATING QUBITS WITH POSITIVE AND NEGATIVE ANHARMONICITIES

A step closer to the Quantum Computer – a processor that helps reduce errors.

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Context

The last decade has seen significant investments in quantum technologies by several state governments around the world as well as in the private sector. Quantum technologies will impact several sectors of the economy such as aerospace, IoT, communication, energy, finance, logistics, pharmaceuticals, and many others. Specifically, if the promise of quantum computers becomes a reality, their market value could reach up to $850 billion in the next 30 years.

This invention is a collaboration between MIT in Boston and the Université de Sherbrooke in Canada. It relates to the interaction between qubits. We present a method to cancel out crosstalk in superconducting quantum processors by alternating between two qubit designs with special characteristics. A superconducting qubit is an electrical circuit composed of superconducting capacitors, inductors and Josephson junctions. This type of qubit is the most prevalent and promising technology in quantum computing.

Description

Currently, quantum processors mostly rely on a specific qubit modality named the “transmon” qubit. By proposing to embed a new qubit modality with opposite anharmonicity to the transmon qubit, we are able to cancel out the undesired interactions in the processor. In addition, this allows us to potentially achieve high-fidelity gates with fewer errors, which is a crucial challenge in the field.

One of the major challenges in realizing a quantum processor is overcoming errors due to unwanted interactions. In a processor based on transmon qubits a common unwanted interaction channel is the so called always-on ZZ interaction, or ZZ-crosstalk. This crosstalk is inherently associated with the physical characteristics of the transmon qubit, mainly its anharmonicity. The anharmonicity of a qubit describes the difference between the transition frequency between the second- and first-state of the qubit, and the qubit frequency. In the transmon qubit, the anharmonicity is negative in value. When coupling two transmon qubits together in an electrical circuit, the two anharmonicities with equal signs combine and result in a large always-on ZZ interaction. This unwanted ZZ interaction limits the gate fidelity and induces errors.

The new proposed superconducting circuit, which we name the “qumon” qubit, is designed to have the same anharmonicity as the transmon qubit but with a positive sign. The qumon qubit is a specific configuration of a family of circuits called the generalized flux qubit (GFQ). The qumon qubit is designed to have the characteristics of a weakly anharmonic oscillator, distinct from other circuits such as the quarton, fluxonium or the capacitively-shunted flux qubit. By coupling a transmon and a qumon qubit together, their two anharmonicities combine, but with opposite signs, therefore they cancel each other out. This cancelation results in suppressing and reducing the always-on ZZ interaction and thus the ZZ-crosstalk. Based on that concept, we can design a new architecture of a superconducting quantum processor with almost zero residual ZZ-interactions, which in turn will enable high fidelity quantum gates and smaller error rates.

Figure 1 shows an extensible architecture in which the ZZ-interactions can be significantly reduced. The blue circles represent the transmon qubits and the red circles represent the qumon qubits. By assembling the two designs in a 2D bipartite lattice of alternating qubit designs, we can realize high-fidelity gates in an extensible superconducting quantum architecture.

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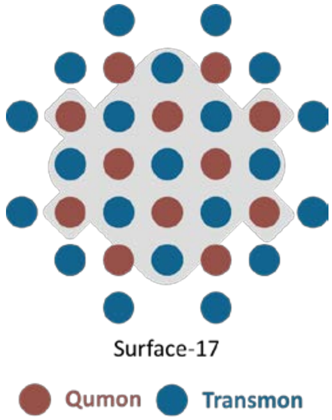

Figure 1. Architecture for zero ZZ-crosstalk for a superconducting quantum processor. Source: Université de Sherbrooke and MIT.

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

- **Cancelation of the unwanted ZZ error** with novel qubit designs – Transmon & Qumon.
- **Extensible architecture** – see figure 1.
- **Suitable for use in large-scale** quantum processors using superconducting circuits.
- **Higher fidelity** than conventional gates, with reduced errors.
- **Reduced** always-on ZZ interaction.
- **Decreased** gate time (no need for ZZ echoing pulse schedules).
- **Larger** qubit-qubit interaction.
- **Allows** direct capacitive coupling.
- In our proposed method, the crosstalk cancelation is embedded into the qubit design itself, hence **reducing the hardware complexity** without any additional active control.
- **Robust to deviations** in the circuit parameters, improving processor-fabrication yield.

Keywords

- Cross-resonance gate, ZZ crosstalk, ZZ interaction, ZZ error, flux qubit, positive Kerr nonlinearity, superconducting circuit, positive and negative anharmonicity.

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 – US 11,615,336 B2.

Seeking

- Commercial partners
- Development partners
- Investments
- Licences

Companies of interest:

- IBM, Google, Amazon, Microsoft, others.

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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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