Design and implementation of a photonic quantum storage device

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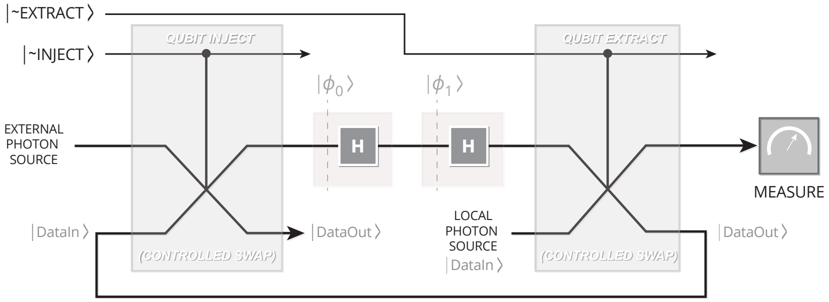
Introduction

The major goal of this research is to produce a practical and scalable quantum memory device. In pursuit of that goal, we expect to leverage (as much as possible) existing semiconductor fabrication technologies and intend for this device to operate at room temperature. In order to achieve these goals, we believe that quantum photonics is currently the only viable candidate.

Quantum Photonics: Opportunity (and Challenges)

There are both significant advantages and fundamental challenges that are inherent in implementing photonic quantum devices. The biggest benefit of a photonic quantum information carrier is its very long decoherence time, due to the photon’s Bose-Einstein statistics. This advantage is also responsible for some of the primary challenges of quantum photonics.

We propose the construction of a "qubit trap", which is a feedback-based photonic quantum memory structure:



Simplified block diagram of the qubit trap

The primary concept is that the photon is not the qubit; it is the information that we need to preserve, not the carrier. However due to the no-cloning theorem, we cannot simply copy the quantum information from one photon to another.

Implementation

We use the structure shown to extract the quantum information from the incoming “external” photons with a controlled-SWAP function. Additional circuitry (not shown) compensates for the difficulties related to the photonic information transfers. Once the qubit is stored in the trap, we leverage the photonic qubits’ very long decoherence times. However, statistics dictate that the “local” photon will be absorbed or scattered at some point. Before that happens, we transfer the quantum information to a “fresh” photon using the same basic C-SWAP mechanism.

Qubit trap feedback is performed in real time during operation in one of two modes (using the same physical data path):

Quantum state feedback *(where qubit information is preserved but not exposed)*
Classical feedback *(where the photon is in a basis state and can be measured)*

In the first case, the incoming photon is in superposition and its final state is not modified as it transits through the qubit trap. In the second case, the incoming photon is evolved back to a basis state and thus, measurement of the photon as it exits the trap will not cause decoherence of other photons in the trap. This structure gives us very fine-grained qubit information access, combined with extremely long decoherence times.

Utility

Long-persistence quantum memory supports the following:

- Multi-pass, “full Deutsch model” Quantum Computation
- Machine learning
- Long-range Quantum Key Distribution & Quantum Networking
- Quantum Radar

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