R&D Theme

Development of hardware control methods and analysis of performance

Progress until FY2022

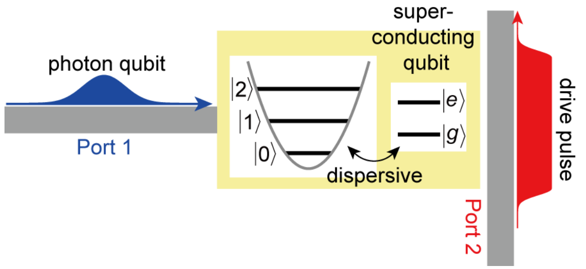
1. Outline of the project

Under this R&D theme, we focus on several physical systems suited for building a fault-tolerant quantum computer. We are trying to capture the unique features of each system quantitatively and to exploit them for proposals of novel implementation methods. We are also developing software such as simulator tools that help to accelerate research on device technology.

2. Outcome so far

1) SWAP gate between superconducting and microwave-photon qubits

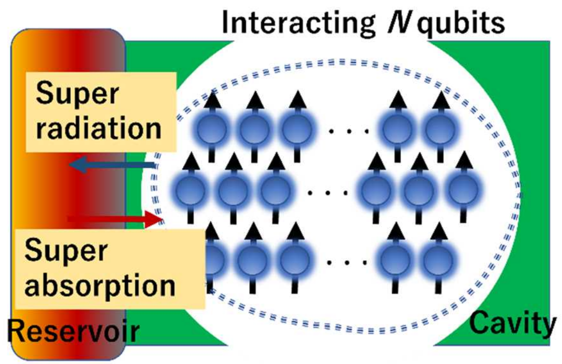
To realize a truly useful quantum computer, it is necessary to connect stationary qubits by using propagating qubits. We theoretically proposed a method to confirm the state



exchange (SWAP gate) between a superconducting qubit and a microwave-photon qubit and demonstrated it in collaboration with an experimental group. The proposed gate can be easily operated by simply reflecting photon qubits onto the superconducting qubits. The average fidelity of photon to atom (atom to photon) state transfer reached 0.829 (0.801). This value can be further improved by extending the qubit lifetime.

2) Exploring novel physical process useful for quantum computing

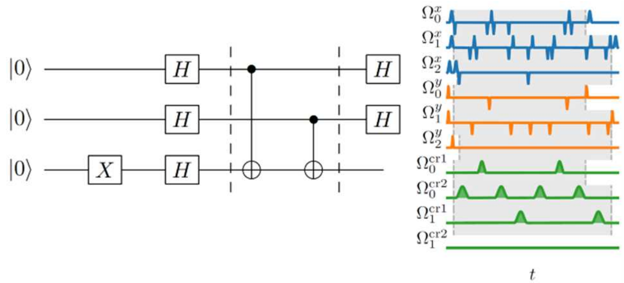
Controlling heat exchange between a system and its environment becomes important as qubits are densely integrated. Super-radiance is a quantum phenomenon that many qubits emit photons synchronously. We have theoretically proved that the reverse process, called "super-absorption," is possible by a proper design of the qubit interaction and the external system. Moreover, for N qubit system, there is a fundamental limit of heat flux that scales with cubic power of N. This process has possible application to the cooling or initialization of qubits in quantum



computers [Phys. Rev. Lett. 2022; Phys. Rev. Lett. 2023].

3) Expanding supporting tools for development of quantum computers

QuTiP (the Quantum Toolbox in Python) is an open-source numerical package for the general simulation of open quantum systems. It has become one of the top quantum numerical packages in the world, surpassing a total of 1,000,000 downloads by the end of 2022. To expedite the use of QuTiP in the research of quantum computers, we released a new package (qutip-qip), which addresses pulse-level simulation of noisy quantum circuits [Quantum 2022].



3. Future plans

We will explore more efficient methods of gate manipulation and state readout with a longer lifetime by applying quantum optical effects for superconducting qubits. We will explore the speed limit of control and measurements and decoherence process of the qubits. We will also continue to develop supporting tools.