DOCTORAL DEFENSE

Quantum Measurement and Bath Engineering for Superconducting Qubits via Multiple Parametric Couplings

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Abstract: Quantum computers have huge potential applications, but do not currently exist. It has already been proved that a quantum computer could outperform the best classical supercomputers in certain problems, some of which have vital connections with our daily life. For example, quantum computers efficiently solve the prime number factoring problem, which in turn is the foundation of the RSA algorithm that is behind almost every online transaction. There is a great deal of current effort to implement quantum computers, and we have seen good progress in platforms including superconducting circuits, ion traps, photons in cavity QED systems and spins in semi-conductors. These machines include up to roughly 50 quantum bits at present, but they are not very useful as quantum errors quickly decohere the computer's state and prevent computation. These errors can be mitigated via quantum error correction, at the cost of additional size and complexity.

Progress in the field towards error corrected, large-scale quantum machines requires us to require new tools for controlling, coupling, and reading out qubits. In this thesis, I will focus on such explorations in superconducting circuits. In this thesis, we seek to expand the already flexible toolkit of quantum circuits by exploring the uses of parametric couplings based on third-order nonlinearities, which have previously been confined to use in quantum-limited amplifiers to create new methods of controlling and measuring quantum bits.

In the first experiment, we address the problem of implementing a high efficient, quantum non-demolition qubit readout. With the use of two-mode squeezed (TMS) light and combining phase-preserving parametric amplifiers into an interferometer for dispersive qubit readout, we demonstrate a measurement scheme with a 44$\%$ improvement in power signal-to-noise ratio. We also investigate the quantum properties of the two-mode squeezed light in the system through a weak measurement protocol and find that tuning the interferometer to be as unprojective as possible was associated with an increase in the quantum efficiency of our readout relative to the optimum setting for projective measurement. The enhancements may enable remote entanglement with lower efficiency components in a system with qubits in both arms of the interferometer.

In the second experiment, we create an effective chemical potential for photons with parametrically system-bath coupling. In particular, we use a lossy Superconducting Nonlinear Asymmetric Inductive eLement (SNAIL) both as the bath and coupler. The bath engineering is realized by combining the multiple parametric drives and the dissipation together. By adjusting the amplitudes of the various parametric drives, we are able to thermalize the qubit to an equilibrium with an arbitrary chemical potential tunable at a controllable rate. Future work will explore the use of this engineered bath to create chemical potentials for lattices of qubits and/or linear resonators, where the need for a way to `fill' the system with a controlled number of photons is sorely needed.

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