MQST Spring Laboratory
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Qubit Control Simulation

Spring quarter 2024

1 Introduction

This document describes a set of projects in the area of Qubit Control Simulation.

2 Superconducting Qubit Control Simulation with QuElements

Relevant literature :

- Daniel A. Lidar, "Lecture Notes on the Theory of Open Quantum Systems", arXiv:1920.00967v2.
- Tripathi, Vinay, et al., "Modeling Low- and High-Frequency Noise in Transmon Qubits iwth Resource-Efficient Measrement", PRX Quantum **5**, 010320 (2024).
- McKay, David C., et al., "Efficient Z gates for quantum computing", Phys. Rev. A, **96**, 022330 (2017).
- Malekakhlagh, Moein, et al., "First-principles analysis of cross-resonance gate operation", Phys. Rev. A, **102**, 042605 (2020).

Also see the QEsim Product Video available on BruinLearn for a high level overview of what their sofware enables you to do.

Procedure:

Using only a Chrome browser, you can access the simulator here :
http://qesim-frontend-ucla-525997421.us-west-2.elb.amazonaws.com/

Refer to the IBM Compute resources listings for actual qubit device parameters to use in setting up your qubit arrays.

Here are some ideas to get started :

- Review the paper by Tripathi et al.
- Understand and reproduce the results in Appendix E Figures 9 and 10, fidelity improvements with dynamical decoupling (DD).
- Simulate your favorite quantum algorithm (D-J, Grover, etc) on various size and topology qubit arrays and evaluate the efficacy of DD for various noise strengths.
- Simulate a logical qubit; initialize the entangled state, perform syndrome extraction, learn about extended rectangles (exRec) and logical gate fidelity simulation.

3 Qubit Control Simulation with scQubits

Time permitting, to complement your work with the QuElements tool, I suggest that you also investigate the scqubits python package from Jens Koch at Northwestern. This allows one to simulate superconducting qubit circuits for a variety of superconducting qubit types. Similar to quElements you specify the physical characteristics of the qubits and their couplings. However their noise models are based on dephasing and deplorizing channels as opposed to the coupling to a bath with dynamics. It would be very interesting to see the tradeoffs between these two approaches !

Relevant literature :

- Peter Groszkowski and Jens Koch, "scqubits: a Python package for superconducting qubits", arXiv:2107.08552v2.
- Chitta, Sai Pavan, et al., "Computer-aided quantization and numerical analysis of superconducting circuits", arXiv:2206.08320v2.