Exercises week 6

Overview

Week 6: Two-qubit gates (fluxonium)

Keywords: Multi-tone drive, low-frequency gates.

[1, Chapters: V, VI B] Long B. Nguyen, Gerwin Koolstra, Yosep Kim, Alexis Morvan, Trevor Chistolini, Shraddha Singh, Konstantin N. Nesterov, Christian Jünger, Larry Chen, Zahra Pedramrazi, Bradley K. Mitchell, John Mark Kreikebaum, Shruti Puri, David I. Santiago, and Irfan Siddiqi. Blueprint for a high-performance fluxonium quantum processor. *PRX Quantum*, 3:037001, Aug 2022

[2, Chapters: I-III, V-VI] Quentin Ficheux, Long B. Nguyen, Aaron Somoroff, Haonan Xiong, Konstantin N. Nesterov, Maxim G. Vavilov, and Vladimir E. Manucharyan. Fast Logic with Slow Qubits: Microwave-Activated Controlled-Z Gate on Low-Frequency Fluxoniums. *Physical Review X*, 11(2):021026, May 2021

E1

Exercises concerning [1]. Here, we will reproduce Fig. 5(c).

(a) Start of by defining all of the relevant parameters which are found in the caption and text.

(b) Define the Hamiltonian for the full composite system $H = H_A + H_B + H_{coupl}$. To be precise, the bare Hamiltonians are given by $H_A = h_A \otimes I_B$ and $H_B = I_A \otimes h_B$ where $I_{A/B}$ is the identity and $h_{A/B}$ is given by Eq. (1). The coupling Hamiltonian is detailed in the caption.

(c) Compute the eigenenergies and eigenstates to reproduce Fig. 5(c)

E2

Exercises concerning [1]. Here, we will simulate the microwave-activated CPHASE gate.

(a) In the previous exercise, we already defined the Hamiltonian of the composite system. The first thing we do is to reduce the dimensions of the matrices that we use in order to speed-up the computations. The idea is to only use the lowest few eigenstates since this is where the relevant dynamics take place. In the composite system, we have four computational states, but we will need to work with a few more states in order to make accurate simulations, so let us say that we work with the lowest $N = 20$ eigenstates. You may want to play around with this number N later to check if the simulation converges. For now, we should compute the lowest 20 eigenstates ψ_i and eigenvalues E_i. We may now express all the operators in this basis $M_{ij} = \langle\psi_i|\,\hat{M}\,|\psi_j\rangle$ where $\hat{M}$ is an operator in the original flux basis such as the Hamiltonian or the drive. The drive Hamiltonian is not directly written in the text, but verify that it is in fact

$$H_{drive} = \mathcal{E}_A(t)\cos(\omega_d t)\,(\phi_A \otimes I_B) + \mathcal{E}_B(t)\cos(\omega_d t)\,(I_A \otimes \phi_B),$$

where the envelope is given between Eq. (18) and (19).

Express H and H_{drive} in the reduced basis consisting of the lowest $N = 20$ states.

(b) By simulating the evolution of a 20x20 identity matrix, you can extract the resulting gate as the top-left 4x4 corner. For a specific set of parameters used in the paper, plot the gate fidelity while varying the drive amplitude $\epsilon_d = \epsilon_A = \epsilon_B$.

References

[1] Long B. Nguyen, Gerwin Koolstra, Yosep Kim, Alexis Morvan, Trevor Chistolini, Shraddha Singh, Konstantin N. Nesterov, Christian Jünger, Larry Chen, Zahra Pedramrazi, Bradley K. Mitchell, John Mark Kreikebaum, Shruti Puri, David I. Santiago, and Irfan Siddiqi. Blueprint for a high-performance fluxonium quantum processor. *PRX Quantum*, 3:037001, Aug 2022.

[2] Quentin Ficheux, Long B. Nguyen, Aaron Somoroff, Haonan Xiong, Konstantin N. Nesterov, Maxim G. Vavilov, and Vladimir E. Manucharyan. Fast Logic with Slow Qubits: Microwave-Activated Controlled-Z Gate on Low-Frequency Fluxoniums. *Physical Review X*, 11(2):021026, May 2021.