Laboratory Exercise 3

CALIBRATING QUBITS USING 'QISKIT PULSE'

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1. Introduction:

Note: For this lab exercise, the values determined in Table 1 below were for the ibmq_manila system as the ibmq_armonk system has been retired. Also, the tutorial code was not edited due to the long queue times on the ibmq_manila system. Results were favoured over originality.

In this report I explore the basics of pulse level control of quantum devices and pulse enabled device calibration data. First, the "Calibrating Qubits with Qiskit Pulse" [1] tutorial is followed to get a basic grasp of pulse level control of quantum devices, and this allows me to demonstrate my understanding of the concepts of relaxation and dephasing times and qubit frequency and anharmonicity. These concepts are quantitatively accounted for through exploration of the tutorial and compared to the calibration data for the same values. A then suitable conclusion is provided to the laboratory exercise.

2. Concepts:

Relaxation Time (or decay time): The two relaxation times explored are T_1 (Energy Relaxation Time) and T_2 (Coherence Time) [2] and their values are seen in Table 1.

T_1 is the time it takes for a qubit to decay from the excited state ($|1\rangle$) to the ground state ($|0\rangle$). It is responsible for limiting the duration of critical programs able to run on a quantum computer [1]. It is measured by applying a π pulse and then a measure pulse after a delay to the qubit. The delay is varied between experiments to visualise the measured signal against delay time. The signal decays exponentially as the qubit approaches the ground state and this time to decay is relaxation time.

T_2 is the timescale over which the qubit's amplitudes of its superposition states become lost or corrupted. [2]. It is measured by the application of a π/2 pulse, a delay, a π pulse, a delay and then another π/2 pulse to the qubit. The π pulse in between the other pulses reverses the accumulation of phase and results in an echo later on. The decay time gives us the coherence time [1].

Dephasing Time: the timescale describing the loss of coherence (ability of the qubit to exist in a superposition state and maintain the phase relationships between quantum states) in the quantum system [2]. It is very similar to T_2 but includes a broader range of dephasing effects.

Qubit Frequency: the difference in energy between the ground and excited states [1]. This frequency is important for creating pulses responsible for applying particular quantum operations on the qubit. It is first calculated by sweeping a range of frequencies and investigating for indicators of absorption. However, this value is a rough estimation, and a more precise value is obtained using a Ramsey pulse sequence: apply a $\pi/2$ pulse, a delay pulse and then another $\pi/2$ pulse. Then the off-resonance pulses are driven by a known amount called the detuning frequency. The measured signal will show oscillations with a frequency near the detuning frequency with a small offset. The small offset is the precise distance the rough estimation was from the precise qubit frequency. This accurate value is seen in Table 1.

Qubit Anharmonicity: describes the nonlinearity in the energy levels of the qubit. Anharmonicity causes the qubit's transition frequency to deviate from its resonant frequency as the qubit transitions between states. This deviation causes an off-resonance component in the qubit's response to the pulses [2]. Anharmonicity makes determining the qubit's frequency more difficult.

3. The Experiment:

Table 1: Table with calibration values for a one qubit system.

Qubit	T_1 (μs)	T_2 (μs)	Frequency (GHz)	Anharmonicity (MHz)
q_0	203.69	128.38	4.960376	3.81

4. Comparison and Analysis:

The estimated qubit frequency, 4.962285 GHz, is very close to the qubit's actual frequency seen in Table 1. It is then reasonable that the sweep was 40 MHz around the estimated frequency.

The maximum time for T_1 was calibrated as 450 μs, which is just more than double the actual T_1 value determined in Table 1. It was then reasonable.

The maximum time for T_2 was calibrated as 200 μs, which is just less than double the actual T_2 value determined in Table 1. It was then reasonable.

The detuning frequency of 2 MHz is slightly more than half the anharmonicity frequency value determined in Table 1. It was then reasonable.

5. Conclusion:

This laboratory exercise focused on pulse level control of quantum devices and pulse-enabled device calibration data. By following the "Calibrating Qubits with Qiskit Pulse" tutorial, we gained a fundamental understanding of relaxation and dephasing times, qubit frequency, and anharmonicity. The estimated qubit frequency closely matched the actual frequency, validating the chosen frequency range for sweeping. The maximum times for T_1 and T_2 were reasonable assumptions regarding the actual values. The detuning frequency used in the Ramsey pulse sequence was slightly higher than half the anharmonicity frequency, allowing for accurate determination of the qubit's precise frequency. Overall, this exercise provided valuable insights into pulse-level control and device calibration.

References:

[1] Calibrating qubits using Qiskit Pulse (2022) Qiskit Textbook. Available at: https://learn.qiskit.org/course/quantum-hardware-pulses/calibrating-qubits-using-qiskit-pulse#importing (Accessed: 25 May 2023).

[2] Nielsen, M. A., & Chuang, I. L. (2010). Quantum Computation and Quantum Information. Cambridge University Press (Accessed: 25 May 2023).