Lab 3 Qubit Measuring and Calibration

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1. Introduction

This report focuses on qubit calibration, specifically the characterization of qubit frequency, anharmonicity, coherence time, and quantum decay time. Accurate calibration of these parameters is essential for reliable and precise quantum computations. Qubit frequency determines the energy spacing between quantum states. Anharmonicity refers to deviations from ideal harmonic behaviour. It impacts gate operations, spectral leakage, and qubit behaviour. Coherence time (T_2) measures how long a qubit retains its quantum state. Qubit relaxation time (T_1) represents the time it takes for a qubit to decay from the excited state to the ground state. This lab will be conducted using Qiskit and the IBM quantum systems specifically on qubit 0 of the ibmq-lima system.

2. Background

2.1 Qubit frequency

Qubit frequency represents the energy spacing between the quantum states of a qubit and is a fundamental parameter in quantum computing (Qiskit IBM, n.d.). It is crucial for gate operations, enabling the implementation of quantum gates, initialization, and readout of qubit states. Qubit frequency is also vital for quantum error correction, calibration, and characterization, as it provides insights into the system's behaviour and allows for optimization. Accurate knowledge and control of qubit frequency are essential for achieving reliable and precise quantum computations in diverse quantum computing architectures.

2.2 Qubit Anharmonicity

Anharmonicity refers to the deviation of a qubit's energy levels from ideal harmonic behaviour (Janssen, 2019). It influences qubit performance and computational capabilities in quantum systems. Determining a qubit's anharmonicity involves a multi-step process. Firstly, a qubit is prepared in its ground state. Then, a series of spectroscopic measurements are performed by applying different frequencies to the qubit and observing the corresponding transitions (Janssen, 2019). By analysing the resulting data, such as the energy-level spacing and transition frequencies, the anharmonicity can be calculated (Janssen, 2019).

2.3 Qubit Timing T_1 & T_2

The T1 time, also known as the relaxation time, characterizes the decay process of a qubit from its excited state to the ground state (Qiskit IBM, n.d.). It represents the time it takes for the qubit to lose its quantum information and return to its lowest energy state (Qiskit IBM, n.d.). The T1 time is a critical parameter as it sets a limit on the duration of meaningful quantum computations that can be executed on a quantum computer. A longer T1 time allows for more stable qubits, enabling longer coherence and the execution of complex quantum algorithms with reduced errors (Janssen, 2019).

The T2 time of a qubit, also known as the dephasing time, measures the duration for which the quantum coherence of a qubit is preserved (Qiskit IBM, n.d.). It quantifies how long the qubit can maintain the phase relationship between its superposition states before it undergoes decoherence (Janssen, 2019).. During the T2 time, the qubit experiences fluctuations and interactions with its environment, causing the loss of coherence and the decay of quantum information (Janssen, 2019). The T2 time is significant because it determines the time window during which meaningful quantum operations can be performed without significant errors (Janssen, 2019). A longer T2 time allows for more robust qubits, enabling the execution of quantum gates and algorithms with improved accuracy.

3. Experimental Results

Table 1: Measured Results

Qubit	T_1 (μs)	T_2 (μs)	Frequency (GHz)	Anharmonicity (GHz)
0	149.48	250,00	5.029747	-0.36

Table 2: IBM Calibration Data for q[0] ibmq-lima

Qubit	T1 (us)	T2 (us)	Frequency (GHz)	Anharmonicity (GHz)
0	126.36	235.11	5.03	-0.33574

4. Discussion

The measured T_1 value was off by about 23ms which is approximately 20% of the given value from IBM in table 2. This can be attributed to the variance in run-to-run qubit parameters as well as imprecise experimental data.

The experiments to measure T_2 were separately unsuccessful, the reasons for this are uncertain as the experiments did not produce data values that could be easily curve fitted. However, taking the average of the two experiments we get a value of $250\mu s$ which is close to the given $235.11\mu s$.

The measured qubit frequency was $5.029747GHz$ this is very close to the given IBM value and presumed to be more precise as it was obtained from the Ramsey Experiment which was run successfully as shown in the notebook.

To measure Anharmonicity, a frequency sweep at a high amplitude was done. What this does is show more transition states of the qubit beyond the ground to excited transition. By taking the difference is frequencies of these extra transition states one can measure the anharmonicity of a qubit (Janssen, 2019). In this case it was measured to be -0.36 which is very close to the given value from IBM.

5. Conclusion

The aim of this lab was to familiarise ourselves with qubit calibration techniques and metrics. This was successfully done using experimental techniques on qubit 0 of the ibmq-lima system as shown in the notebook.

5. References

[1] Janssen, L.M. (2019). *Characterisation of Transmon Qubit Chips*. [online] *TUDelft*. Available at: https://repository.tudelft.nl/islandora/object/uuid:73cbbe3c-8021-4e85-9512-948baf828ff4 [Accessed 25 May 2023].

[2] Qiskit IBM (n.d.). *Calibrating Qubits Using Qiskit Pulse*. [online] learn.qiskit.org. Available at: https://learn.qiskit.org/course/quantum-hardware-pulses/calibrating-qubits-using-qiskit-pulse#T1 [Accessed 25 May 2023].