ELEN4022 Lab 3

Jess Dworcan (1924564)
School of Electrical and Information Engineering, The University of the Witwatersrand,
Private Bag 3, 2050, Johannesburg, South Africa.
1924564@students.wits.ac.za

***Abstract*—The decoherence of the IBM Brisbane quantum computer is measured in this lab exercise. These T_1 and T_2 times, as well as the frequency of a single qubit, are measured. Measurements are taken in two sets, the first set being an hour after calibration and the second being two hours post-calibration. The T_1 measured is longer when measured closer to calibration time. The level of accuracy of the result of T_2 diminished considerably in the second test. The decoherence of the quantum computer is found to be much greater many hours after calibration.**

I. Introduction

Physical qubits can only hold onto a state for a finite time, called coherence time[1]. After that, the qubit loses coherence and goes from a desired state to a random, useless state in a process called 'Decoherence'. The coherence time of a qubit needs to be long enough for all gates in a quantum circuit to be executed when running any algorithm that yields an accurate desired result.

Two commonly used ways to measure coherence time are relaxation (T_1) and dephasing (T_2) time[1]. T_1 relates to the qubit's loss of energy as it goes from the excited state of $|1\rangle$ to the ground state, $|0\rangle$. This energy is transferred into the environment. T_1 can be seen as the longitudinal decoherence, going from the south to the north pole of the block-sphere, whereas T_2 can be seen as the latitudinal decoherence. T_2 relates to the drift in phase over time. Specifically, T_2 is defined as the time it takes for a qubit's resonant frequency to become unidentifiable[2].

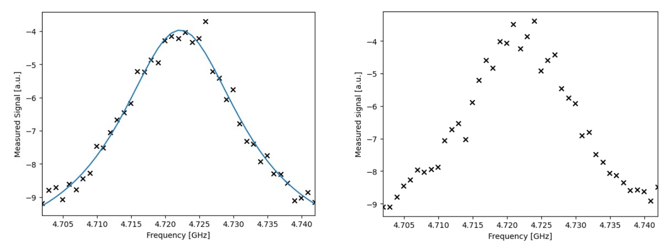
The code used to conduct the frequency sweep and experiments that follow is heavily influenced by the Qiskit textbook [3] chapter "*Calibrating qubits using Qiskit Pulse*". A frequency sweep is done, followed by the Rabi, T_1, Ramsey and T_2 Han Echo experiments. A conclusion is made on the decoherence of the quantum architecture.

II. Qubit Calibration Tests

The calibration testing of a qubit is performed on the IBM Brisbane quantum computer. Two sets of results are taken. The first set of results is taken 1 hour after calibration of the machine, and the second is taken six hours after the first.

A. Frequency Sweep

A frequency sweep is performed on the machine. In the first test, the estimated frequency is found to be 4.7219066 Hz; in the second test, it is found to be 4.7219085 Hz. The sweep is done for the range 4.7019 GHz to 4.7419 GHz in steps of 1.0 MHz. The frequency is measured over a bandwidth of 40 MHz and in steps of one MHz. The frequency distributions of the two tests are shown in Figure 1a and 1b. The measured frequencies of the first and second tests are 4.7221 GHz and 4.7392 GHz, respectively. The distribution of the second result is considerably noisier than the first.

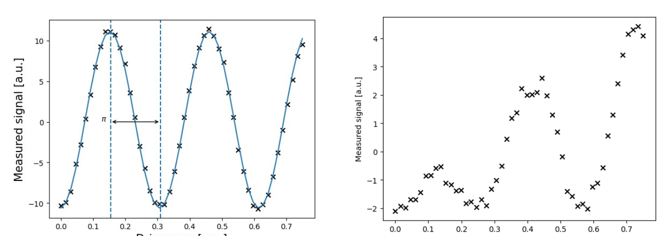


(a) One hour after calibration (b) Seven hours after calibration

Fig. 1: Comparison of frequency sweep results.

B. Rabi Experiment

The Rabi experiment traverses the qubit over the longitudinal edge by π rotations, essentially performing a bit-flip taking the qubit from $|0\rangle$ to $|1\rangle$[3]. The test measures the magnitude of the qubit over a range of drive pulses. The qubit is bit-flipped more than once. The first result, in figure 2a, shows a sinusoidal signal, oscillating evenly between zero and one. The second result, in figure 2b, shows a sinusoid that reaches higher amplitude oscillations for increasing drive pulse. The result shows that the signal reaches $|0\rangle$ after every oscillation but takes a higher drive pulse to reach $|1\rangle$.

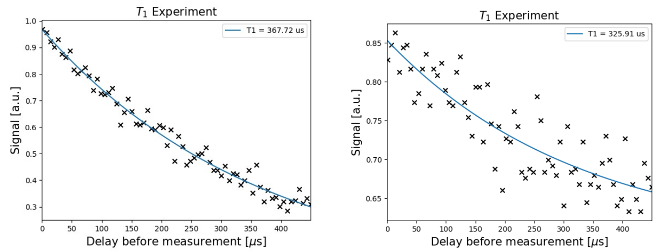


(a) One hour after calibration (b) Seven hours after calibration

Fig. 2: Comparison of Rabi experiment results.

C. T_1 Experiment

The T_1 experiment is performed on the qubit. The results are shown in figures 3a and 3b. A drive pulse is sent out, followed by measured pulses, delayed at even intervals. The experiment shows the amplitude decay of the drive pulse at the moment of each delayed measurement pulse. The second result shows a much more varying decay than the first result's steady decay.



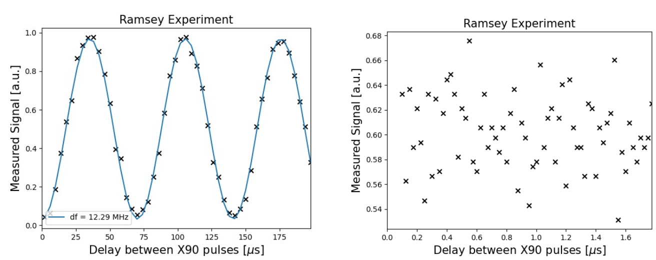
(a) One hour after calibration

(b) Seven hours after calibration

Fig. 3: Comparison of T1 experiment results.

D. Ramsey Experiment

The Ramsey pulse sequence is done to measure the qubit frequency more accurately[3]. The experiment first applies a $\frac{\pi}{2}$ pulse, then waits some short time Δt followed by another $\frac{\pi}{2}$ pulse. The frequency of the $\frac{\pi}{2}$ pulse is measured at the same frequency as the qubit, so any oscillation in the Rabi experiment will determine if the previously measured frequency value is off the mark and by how much. The first result, in figure 4a, gives a more accurate frequency of 4.7118 GHz. The second result, in figure 4b, gives a more accurate result of 4.7371 GHz; however, the graph is shown to be much noisier than the first result of the Ramsey test.



(a) One hour after calibration

(b) Seven hours after calibration

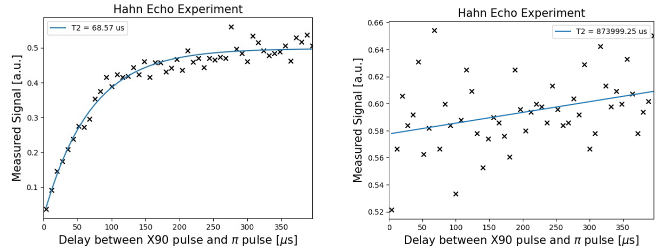
Fig. 4: Comparison of Ramsey experiment results.

E. T_2 Han Echo Experiment

The Han Echo experiment is similar to the Ramsey experiment except it contains the addition of a π pulse sometime τ after the initial $\frac{\pi}{2}$ pulse. This causes the phase errors to reverse, resulting in an echo at time 2τ when a measurement is taken. The echo shown in figure 5b, taken seven hours after calibration, does not resemble the more accurate result in figure 5a, taken one hour after calibration.

III. Results

The results for T_1, T_2 and qubit frequency are shown in table I.



(a) One hour after calibration

(b) Seven hours after calibration

Fig. 5: Comparison of Han Echo experiment results.

TABLE I: Table of qubit decoherence results

Time after calibration	Qubit	T1 (us)	T2 (us)	Frequency (GHz)
1 hour	q0	367.72	68.57	4.7118
7 hours	q0	325.91	873999.25	4.7371

IV. Discussion

The results taken one hour and seven hours after calibration of the IBM Brisbane quantum computer differ vastly. The second set of results shows a lot more decoherence than the first set, illustrating a considerable loss in the accuracy of the quantum computer. The T_1 time of the second set is shorter than the first, showing it takes less time for a qubit to lose its energy. Also, the second result for T_2 is much longer than the first, by a few orders of magnitude. The result that is expected is for T_2 to be less than T_1, like in the case of the first result. This shows a huge inaccuracy in the quantum computer, likely due to a drop in performance and noise.

V. Acknowledgements

The results used in this experiment were jointly generated by colleagues in the ELEN4022 course. The first results were taken from student 2333213 and the second from student 1924564.

VI. Conclusion

The decoherence of the IBM Brisbane quantum computer is measured in this lab by conducting a frequency sweep as well as the Rabi, Ramsey, T_1, and T_2 Han Echo experiments. The level of accuracy of the quantum computer is commented on based on the two sets of results that were recorded. The conclusion is that the accuracy of the machine diminishes considerably within seven hours of calibration.

REFERENCES

[1] R. S. Sutor, *Dancing with Qubits: How quantum computing works and how it can change the world*. Packt Publishing Ltd, 2019, ISBN: 1-83882-525-8.

[2] R. Youssef, "Measuring and simulating t1 and t2 for qubits," Fermi National Accelerator Lab.(FNAL), Batavia, IL (United States), 2020.

[3] Qiskit. "Textbook/notebooks/quantum-hardware-pulses/calibrating-qubits-pulse.ipynb at main · qiskit/textbook," GitHub. (), [Online]. Available: https://github.com/Qiskit/textbook/blob/main/notebooks/quantum-hardware-pulses/calibrating-qubits-pulse.ipynb (visited on 05/17/2024).