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ELEN4022: Full Stack Quantum Computing
Lab 3

1.Introduction

Frequency and anharmonicity of qubits, as well as the decoherence times, relaxational and dephasing times can affect the results of our circuits when running them on quantum computers. This report will explain these terms and run some experiments on the lima quantum computer of IBM and find the values of these. These measurements will be done using code from qiskit [1]which needed to be slightly changed to match up with the quantum system used. The quantum system used for these experiments is the Lima system from IBM and the first qubit or qubit 0 was used for all testing.

2. Decoherence Times

Decoherence times is the time it takes a quantum qubit to lose its coherence or its information as the qubit slowly shift from the ground state to the excited state and vice versa. The relaxation times are another name for decoherence times, these are the T1 and T2 values which will be calculated later. T1 is the energy relaxation time, is the time that a qubit takes to transition from an excited state to a ground state [2]. This tells us about the rate at which the qubit dissipates energy [2]. T2 is the phase relaxation time or also called the dephasing time. This is the time that a qubit can lose its phase in between the quantum states [2]. This measures the rate at which the superposition state gets disrupted due to various noise sources [2].

T1 relaxation time can be measured by first doing preparing the qubit in the excited state than waiting for some time and then measure the state. We then repeat these many times with different wait times before measurement. The decay time of the resulting graph is out T2 relaxation time [3]. During the wait times the qubit energy is changing or dissipated and slowly moving to the ground state.

T2 relaxation time can be measured by first preparing the qubit to the ground state. Thereafter apply a $\pi/2$ pulse, then wait for some time and do a π pulse and thereafter another $\pi/2$ pulse and measure the qubit. The π pulse reverses the accumulation of phase and results in an echo at double the wait time [1]. Then repeat this process with different wait times between the pulses [3]. During the wait times the qubits phase is changing. The decay time of the experiment is then the T2 time measured.

3. Frequency and Anharmonicity

Frequency of a qubit refers to the energy difference between the two quantum states being the excited and ground states or |1> and |0> states. Qubits do have higher energy states but these systems are fabricated so that the system is anharmonic and so we isolate these two states and ignore the higher energy states [4]. We can measure the frequency by exerting pulses of different frequency onto the qubit and looking for absorption.

Anharmonicity is the deviation from the ideal harmonic behaviour in quantum systems. Anharmonic is when the spacing between different energy levels in a qubit is different and not equal. These quantum computers are deliberately made to be anharmonic so that we can control which transitions we are exciting [1]. This isolates the two energy levels we require and ignores the higher energy levels [1].

4. Results

Table 1: Measured and calibrated values

	T1 (μs)	T2 (μs)	Frequency (GHz)	Anharmonicity (GHz)
Measured	117.77	192.07	5.02968GHz	0.00194
Given by IBM	123.17	186.08	5.03	-0.33574

As can be seen from the above results, the values that were measured are very close to the values that are given on IBM's website for the calibration values. The only value that is incorrect is the anharmonicity, this can be due to the anharmonicity tests being incorrect, this could also be due to incorrect calibration or that calibration was done long ago and so the quantum system has shifted from calibration and needs to be recalibrated again. This shows that most of the measurements and testing were successful, and the correct values were measured except for anharmonicity which needs some more work to get working correctly.

Conclusion

This report highlights some important concepts in quantum computers, namely, decoherence times, frequency of qubit and anharmonicity. This experiment was mostly successful as the measured results were like those calibrated values given by IBM. The only errors were found in the anharmonicity measured amount. The T1 and T2 relaxation times were measured, and their meanings explained which helps in understanding how they affect how quantum computers run and their results produced.

References

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[4] M. Pita-Vidal, A. Bargerbos and R. Zitko, "Direct manipulation of a superconducting spin qubit strongly coupled to a transmon qubit," *Nat. Phys,* 2023.