Contribution ID: **71** Type: **"Rapid fire" talk**

Development and Analysis of Transmon Qubits for Quantum Sensing applications

Monday, 17 March 2025 16:45 (7 minutes)

Superconducting transmon qubits have emerged as powerful tools for precision sensing applications [1, 2], particularly in the search for light dark matter candidates such as axions and hidden photons [3–9]. These weakly interacting particles may leave detectable signatures through their coupling to electromagnetic fields, making highly sensitive quantum devices essential for their discovery. Transmon qubits, with their exceptional coherence properties and strong interaction with microwave photons, offer a unique approach to detecting such exotic weak signals.
In this contribution, we describe how transmon qubits can be employed as quantum sensors for light dark matter detection, focusing on their role in probing weak microwave signals that could originate from axion-photon or hidden photon conversions. We then present our efforts to design, simulate, and validate transmon qubit parameters with the goal of developing a light dark matter detector.
To achieve this, we employed state-of-the-art simulation techniques such as the Lumped Oscillator Model [10] and the Energy Participation Ratio method [11] to accurately predict the key parameters of fixed-frequency and tunable transmon qubits. These parameters include transition frequencies, anharmonicity, and coupling strengths, all of which are crucial for maximizing sensitivity to potential dark matter-induced signals.
We then conducted cryogenic measurements of fabricated qubits and compared their experimental performance with theoretical predictions. The measurements focused on qubit coherence times, transition frequencies, couplings, as these properties directly impact the detection sensitivity to weak electromagnetic signals. Our results indicate a strong correlation between simulated and experimental data. However, deviations caused by fabrication-induced inhomogeneities and setup limitations highlight the need for further refinements in device engineering.
Future efforts will focus on improving fabrication processes and refining theoretical models to further enhance detection sensitivity and mitigate sources of noise.

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Session Classification: Quantum sensors and technologies

Track Classification: Quantum sensors and technologies