Development and Analysis of Transmon Qubits: Design, Simulation, and Characterization

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Abstract: We investigated simulation techniques for superconducting transmon qubits, comparing their predictions with experimental results. The promising agreement observed highlights the potential of these methods to guide the design of qubits for quantum sensing applications.

In this contribution, we describe our efforts to design and validate superconducting transmon qubits intended for quantum sensing applications. These devices are of great interest for their ability to detect weak electromagnetic signals, such as those expected in axion and dark photon searches [1-9]. A key challenge in this context is ensuring that the qubit parameters obtained after fabrication closely match the intended specifications. Therefore, reliable simulation techniques are essential to improve the design process and reduce iterative prototyping.

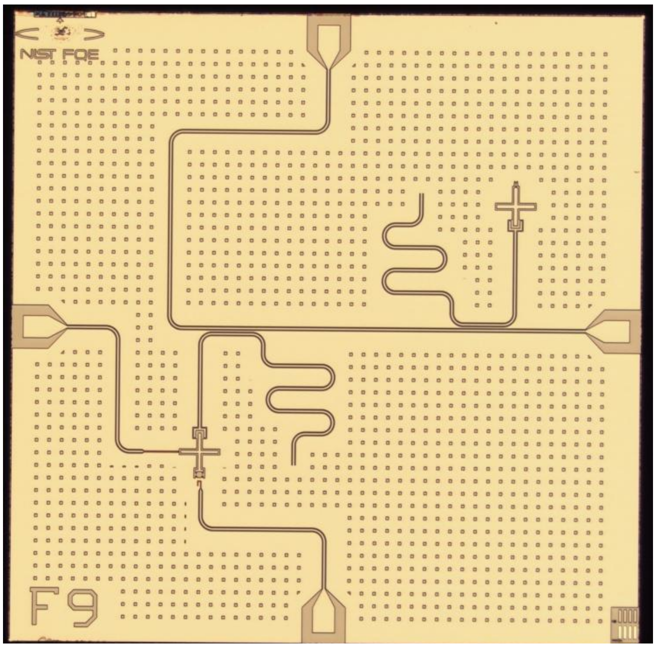

Figure 1 Picture of the fabricated two qubits device

We applied established simulation techniques, including the Lumped Oscillator Model [8] and the Energy Participation Ratio method [9], to predict key qubit properties such as transition frequencies, anharmonicity, and coupling strengths. Two types of transmon qubits were considered: single-junction fixed-frequency qubits and tunable-frequency qubits based on SQUIDs. The predicted parameters were compared with measurements obtained from the fabricated devices at cryogenic temperatures.

The results showed reasonable agreement between the simulated and experimental parameters, indicating that the applied models can provide valuable guidance in qubit design. While some deviations were observed, these could be attributed to imperfections in material properties and the fabrication process. Despite these limitations, the simulations allowed us to predict critical trends and refine the device design accordingly. We characterized the performance of both fixed and tunable qubits, with particular attention to their coherence times and transition frequencies, which are crucial for their operation in quantum sensing.

This study highlights the usefulness of simulation-driven design in the development of superconducting qubits. While further refinements are needed to improve accuracy, the presented methods already offer a practical approach to guiding the fabrication of devices for specific sensing applications. Future work will focus on enhancing the modeling techniques by incorporating more detailed information about material properties and environmental effects. Our goal is to further reduce the gap between predicted and experimental results, ultimately leading to more reliable and efficient qubit-based quantum sensors.

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