

Advances Toward Scalable Superconducting Qubit Systems

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Abstract: We report advances in superconducting qubit-based sensing for ultralight dark matter, including ancilla-assisted detection protocols and single-photon schemes, alongside characterization of a two-qubit prototype with improved coherence, reduced linewidth, and scalable readout capabilities.

We report on recent advances in research conducted at the University and INFN Unit of Milano-Bicocca on the development of superconducting qubit-based sensing applications. In particular, we present novel detection schemes for the search for ultralight bosonic dark matter. The first scheme is based on an ancilla-assisted, gate-based protocol that enhances sensitivity to the hidden-photon kinetic-mixing parameter ϵ using a single two-qubit gate. This approach bypasses the need to maintain long-lived multi-qubit entangled states and remains compatible with the limitations of current quantum hardware [1]. The second scheme is based on a quantum sensing experiment in which an itinerant single photon, propagating along a transmission line and reflecting off a microwave cavity, acquires a qubit-state-dependent phase shift, thereby mapping the photon's presence onto the qubit state [2]. This mechanism enables scalable readout with a reduced dark-count rate and has been experimentally validated on a single-qubit 3D device but never on planar configuration; the design is currently under production at National Institute of Standards and Technology (NIST) microfabrication facility.

Finally, we report on the characterization of a preliminary prototype of a two-qubit device that can function both as a quantum gate and as a single-photon detector in the microwave regime. The device has been designed at the Bicocca laboratories, fabricated at NIST, and fully measured at the Bicocca laboratories. An improved experimental setup, including on-chip wire bonding supported by enhanced simulations, and a quantum-limited readout, has reduced the resonator linewidth by a factor of two. This brings simulations into agreement with measurements and yields two high-coherence qubits with T_1 consistently exceeding 60 μs and peak values reaching 100 μs .

On the control side, we are actively developing a custom multi-RFSoc synchronization via Qibosoq [3] and customizing firmware to support our evolving experimental requirements.

References

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