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DOI

[10.1051/epjconf/202533506012](https://doi.org/10.1051/epjconf/202533506012)

Publication date

2025

Document Version

Final published version

Published in

EPJ Web of Conferences

Citation (APA)

Warner, H. K., Rajabali, S., Park, S., Rolon-Gomez, N., Witt, D., Yacoby, A., & Lončar, M. (2025). Tunable superconducting microwave resonator for quantum transduction. *EPJ Web of Conferences*, 335, Article 06012. <https://doi.org/10.1051/epjconf/202533506012>

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Tunable superconducting microwave resonator for quantum transduction

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Abstract. This work presents a superconducting microwave resonator that is both frequency tunable and compatible with photolithography. This design is well-suited for integration with electro-optic devices. We demonstrate tuning ranges exceeding 500 MHz, using a bulk permanent magnet, and 100 MHz, using planar coils, under moderate magnetic fields (below 5 mT).

1 Introduction

Integrating superconducting and photonic components has become essential in advancing a wide range of quantum systems [1–3]. Such superconducting resonators enable resonant enhancement of frequency-mixing processes in transducers. However, frequency resonance matching is a challenging task across multiple system modes. To overcome this limitation, we present a frequency-tunable superconducting microwave resonator that functions as a reconfigurable link in hybrid systems to satisfy resonance conditions and improve electro-optic device performance.

2 Results

The resonance frequency of an LC superconducting resonator can be adjusted by tuning the circuit's inductance (L). In our design, the incorporation of holes within the meander inductor structure enhances magnetic flux penetration and allows dynamic control over the kinetic inductance—and thereby the resonant frequency—of the device. We selected niobium as the superconducting material, which is compatible with microwave-optical devices on our electro-optic platform (more details on the fabrication in ref [4]). Figure 1 shows the image of the resonator and transmission spectrum of the device measured above and below the critical temperature ($T_c \sim 9$ K), revealing a distinct resonant mode near 6.57 GHz.

Here, two tuning mechanisms are explored at 4K. We begin by illustrating frequency tuning with a permanent magnet mounted on a movable rod inside the cryostat. The resonator transmission under varying magnetic fields shows tuning over 500 MHz with an estimated applied magnetic field below 5 mT. The changes in the resonance lineshape are attributed to coupling with box modes within the silicon substrate.

In the second tuning method, we fabricate planar magnetic tuning coils by depositing niobium onto silicon using the same fabrication techniques for microwave resonators. The planar tuning chip is positioned directly beneath the microwave resonator chip and roughly aligned

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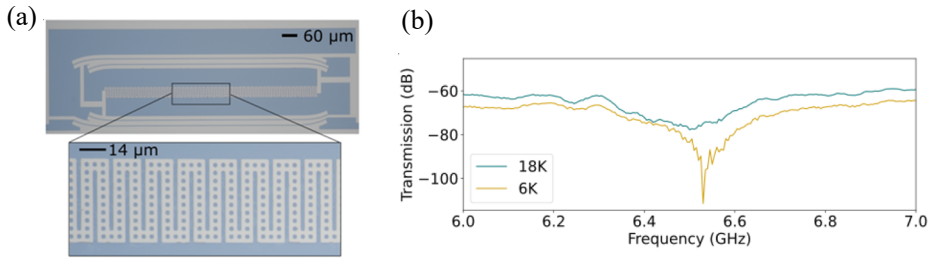


Figure 1. (a) Optical micrograph of niobium LC resonator (tan) on silicon (blue). (b) Transmission through a niobium microwave resonator above T_c (18K) and below T_c (6K).

using alignment marks. To reduce the substrate thickness, the backside of the microwave resonator chip is polished, causing a blue shift in the resonant frequency. We then inject a DC current via probes in the tuning coils, to induce a magnetic field. The maximum applied current is 100 mA, resulting in 100 MHz of tuning. The observed tuning curve is sinusoidal with a spike near 40 mA, which we attribute to the current-induced local tuning of the kinetic inductance in the niobium film. This effect could potentially be mitigated by increasing the nanowire width or thickness. Result of both tuning methods are presented in figure 2.

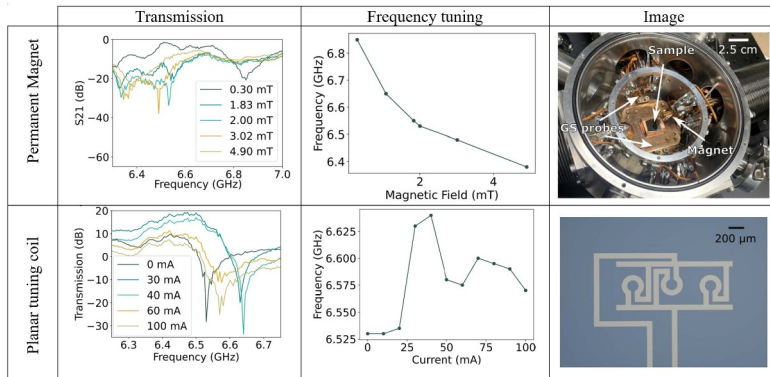


Figure 2. First row: C1) Microwave resonator transmission taken at different estimated magnetic fields applied by a permanent magnet. C2) Microwave resonant frequency as a function of estimated magnetic field. C3) Setup for characterizing device tuning. A magnet (right) mounted on a movable arm is used to inject magnetic field into the inductor. Second row: C1) Microwave resonator transmission at different injected currents, and thus magnetic field, in the planar tuning coils. C2) Microwave resonant frequency as a function of injected current into the planar coil positioned beneath the resonator chip. C3) Planar LC tuning coils, where three niobium loops in parallel (tan) are placed below the tunable microwave resonator to induce magnetic field in the inductor

References

- [1] Y. Liu, et. al., “Coherent memory for microwave photons based on long-lived mechanical excitations,” *NPJ Quantum Information*, **9** (2023).
- [2] E. Eisenach et. al., “Cavity enhanced microwave readout of a solid-state spin sensor,” *Nature Communications*, **12** (2021).
- [3] J.M. Gambetta, J.M. Chow, M. Steffen, “Building logical qubits in a superconducting quantum computing system,” *NPJ Quantum Information*, **3** (2017).
- [4] H. K. Warner, et. al, “Coherent control of a superconducting qubit using light,” *Nature Physics* (2025).