CHALMERS UNIVERSITY OF TECHNOLOGY

Department of Microtechnology and Nanoscience (MC2)
Quantum Technology Lab, Wieczorek Group
www.wieczorek-lab.com

Master Thesis Project

Superconducting resonators for macroscopic quantum experiments

Background:

What are the limits of quantum mechanics? To explore this, we aim to bring a macroscopic particle into the quantum regime[1]. To do so, we magnetically levitate a micrometer-sized particle using on-chip coils[2,3].

For quantum control of this levitated particle, we need to cool the particle's center-of-mass to its motional ground state (~nK) using feedback cooling[4].

For this, the particle's motion must be coupled to a flux-tunable resonator such as a superconducting coplanar waveguide (CPW) terminated with a DC-SQUID. A ground-state cooled levitated micro-particle can also be used for quantum sensing of force, acceleration, and gravity[1,4,5].

Thesis Goals:

- **Flux transformer design:** Maximize the transfer of flux signal to the SQUID resonator via design optimization and fabrication techniques like flip-chip and on-chip coil, multi-winding, washer SQUIDs, etc.
- **Resonator design:** Reduce the non-linearity of the resonator by designing and fabricating micron-sized Josephson junctions or SNAILs.
- **Flux Coupling:** Demonstrate flux-mediated coupling of a magnetically levitated microparticle to a superconducting resonator.

What we offer:

- The skills to design and analyze superconducting microwave circuits, SQUID-based CPW resonators, and flux transformers.
- A rich cleanroom experience in fabricating Josephson junctions, SQUID-based resonators, and flip-chip interconnects using state-of-the-art tools at MC2.
- Training on electromagnetic simulation using ANSYS HFSS
- Experience with mK cryogenics on BlueFors dilution refrigerator
- Microwave spectroscopy and control of superconducting devices

Thesis expectations:

- The aim is to make the student independent such that they can drive the project on their own and formulate ideas and solutions

[1] O. Romero-Isart, et al., Physical Review Letters, 109, 147205, 2 (2012).
[2] M.G. Latorre, et al., IEEE Trans. on App. Supercond. 32, 1-5 (2022).
[3] M.G. Latorre, et al., Phy. Rev Applied, 19(5) (2023).
[4] M. T. Johnsson, et al., Scientific Reports, 6, 37495, 5-9 (2016).
[5] J. Prat-Camps, et al. Physical Review Applied, 8, (2017).

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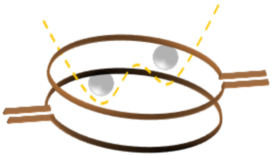
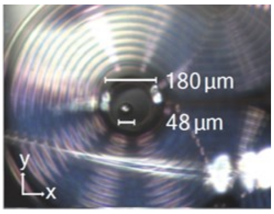
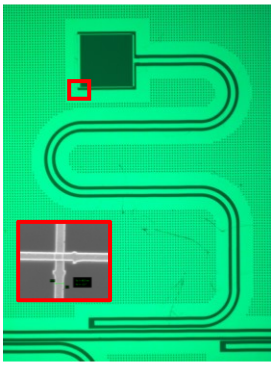


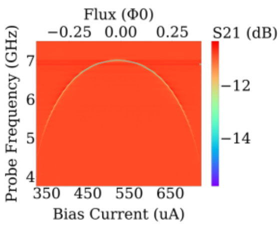
Cartoon of a levitated microparticle in the quantum regime exhibiting macroscopic quantum superposition



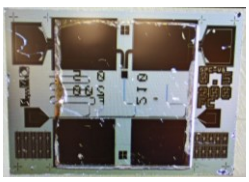
Optical image of an on-chip magnetic levitation trap with a 48 µm particle inside



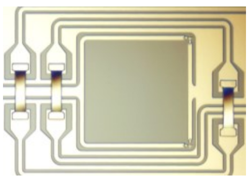
Optical image of a fabricated CPW resonator shunted with a DC-SQUID. The inset ishows a Josephson junction



frequency tuning of a SQUID resonator via external magnetic flux



SQUID resonator flux-coupled to input coil using flip-chip interconnects



SQUID resonator flux-coupled to a multi-winding input coil using air-bridges

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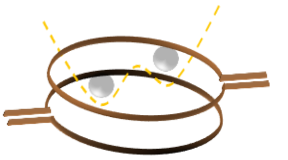
Master Thesis Project

Vibration Isolation Stage for Quantum Experiments at mK Temperature



Cartoon of a levitated microparticle in the quantum regime exhibiting macroscopic quantum superposition

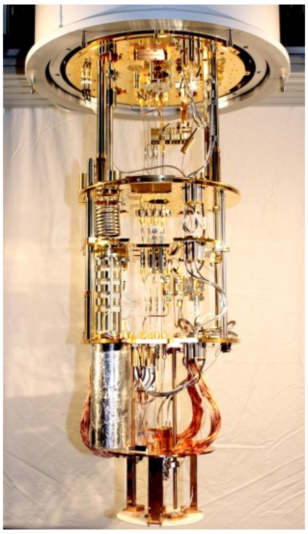
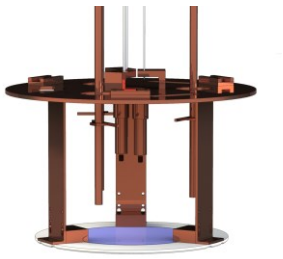
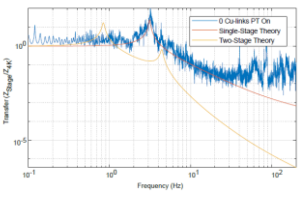


Photo of a BlueFors dilution refrigerator with the current single-stage isolation system



CAD model of the single-stage isolation with the experiment sitting on the bottom (blue). The springs are attached to the nylon wires at the top (white)



Transmissibility of a two-stage system

Background:

A levitated microparticle is a promising platform for quantum sensing as it is maximally isolated from the environment. This makes it highly sensitive to forces on the order of zeptonewton and thus can be used to detect, for example, weak gravitational signals. We levitate superconducting particles using magnetic fields. Inside this magnetic field, the particle oscillates at a frequency of a few hundred Hz.

The entire experimental setup (see image) is placed inside a high vacuum (10^{-6} mbar) dilution refrigerator that cools the system down to 20 mK. However, external mechanical vibrations excite the particle and increase its effective temperature.

To dampen these vibrations, we have built a single-stage passive spring-mass system that gives a 20 dB attenuation in the amplitude of particle motion. However, for reaching the ground state, we need the noise to be below 60 dB. For this, we need a multi-stage vibration isolation setup.

Thesis Goals:

- Design, analyze and simulate a multi-stage vibration isolation system
- The stage must be mechanically isolated but well-thermalized to the fridge
- Noise damping from the fridge and surrounding must be at least 60 dB at all frequencies above 100 Hz.
- Experimentally test the damping characteristics of the stage.

What you will learn:

- Vibration dynamics in cryogenic environment for quantum applications
- Design and thermalization of passive components for given constraints
- Working in experimental physics with an interdisciplinary team

Desired skills:

- Structure Dynamics, Control Systems, dynamic simulation (e.g., ANSYS Mechanical), CAD (Creo, Solidworks), basic coding (Python, MATLAB)

[1] Leng, Y., et al. (2021). Mechanical dissipation below 1 µHz with a cryogenic diamagnetic-levitated micro-oscillator. Physical Review Applied, 15(2), 024061 10.1103/PhysRevApplied.15.024061
[2] de Wit, M., et al. (2019). Vibration isolation with high thermal conductance for a cryogen-free dilution refrigerator. Review of Scientific Instruments, 90(1), 015112 10.1063/1.5066618

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