Graduate School Event

Thesis Defense: High-Impedance Circuits for Mesoscopic Physics. Geometric Superinductors and Insulating Josephson Chains.

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Host: Latha Venkataraman

Quantum mechanics reveals a world that defies classical determinism, where uncertainty, superposition, and fluctuations are fundamental aspects. Engineering devices that harness these quantum features requires not only precision, but also a deep understanding of how they interact with their surrounding environment. Superconducting circuits, which exploit macroscopic quantum coherence in low-loss superconducting materials, provide a scalable platform for implementing such systems. Among the critical elements in these circuits, superinductors—high-impedance, dissipation-free inductive components—play a central role by suppressing charge fluctuations. They allow quantum states to be delocalized in phase space, protect qubits from environmental noise, and facilitate access to phenomena such as dual Josephson physics and ultra-strong coupling regimes.This thesis explores two complementary implementations of high-impedance circuits: geometric superinductors, demonstrating that high impedance can be achieved beyond kinetic inductance, and Josephson junction chains, used to investigate both microwave mode properties and DC transport across the superconducting-to-insulator transition.Part I addresses geometric superinductors. Contrary to the common belief that high-impedance superconducting circuits require kinetic inductance, we demonstrate that purely geometric designs can achieve characteristic impedance exceeding the resistance quantum. By exploiting mutual coupling between adjacent turns, coil-based inductors achieve enhanced self-inductance, creating a reliable platform for qubits and resonators. Modeling, simulation, fabrication, and characterization confirm that these elements behave as superinductor. With low loss, high linearity, and minimal stray capacitance, these elements are reproducible, free of uncontrolled tunneling events, and capable of strong magnetic coupling. This establishes geometric superinductors as robust, single-wave-function superconducting devices suitable for hardware-protected qubits and hybrid systems.Part II presents classical numerical simulations of a QPS circuit to study dual Shapiro steps.Part III extends the investigation of high characteristic-impedance circuit elements to one-dimensional Josephson junction chains, which act as a quantum simulator for many-body physics and the superconductor–insulator transition. Different devices are realized on both sides of the DC phase transition, showing either a supercurrent branch or Coulomb blockade at zero bias. The effect of the crossover on microwave modes,

however, remains insufficiently investigated. Studying these modes provides insight into the interplay between disorder and phase-slip events. Small differences in circuit component sizes determine which side of the transition a device falls on, make these results relevant not only for fundamental understanding but also for the design of quantum devices, emphasizing the crucial role of the electromagnetic environment in stabilizing and controlling fragile quantum states.Together, these results illustrate how carefully engineered high characteristic-impedance elements provide a link between macroscopic circuits and the inherently uncertain quantum world, enabling experiments that probe, control, and ultimately exploit quantum fluctuations for applications in quantum information, metrology, solid state physics and beyond.

Friday, August 29, 2025 03:30pm - 04:30pm

Office Bldg West / Ground floor / Heinzel Seminar Room (I21.EG.101) and Zoom

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