Superinductor-based Quantum Technologies with Ultrastrong Couplings (SiUCs)

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Introduction

Superconducting qubits have become one of the most promising platforms on which to build the entire span of quantum technologies. The success of this technology lies in the mastering of the interaction between light and matter, framed in field named circuit quantum electrodynamics (circuit QED), where microwave photons play the role of light, while qubits effectively behave as artificially man-made atoms.

The light-matter models used by the community of superconducting quantum circuits are inherited from atomic physics, where interaction strengths are very small and the rotating-wave approximation (RWA) is fully justified. This unavoidably represents a limitation when the whole physical model is required to accurately explain the results of experiments. The general light-matter interaction model is the quantum Rabi model (QRM):

\[ \hat{H}_{\text{QRM}} = \frac{\hbar}{2} g(\alpha \hat{a} + \frac{1}{2}) + \hbar g \hat{a} (\hat{a} + \hat{a}^\dagger) \]

containing much richer physics, but a very large interaction strength - also known as ultrastrong coupling (USC) - is required. Very few experiments have so far attained such levels of light-matter interaction [Forn-Díaz2010, Niemczyk2010, Yoshihara2017]. Despite this, the interest in USC physics has grown worldwide in the last decade.

Goals of project SiUCs

SiUCs aims to answer the following questions:

1. Can non-RWA effects be completely disregarded in conventional experiments of superconducting circuits exploring quantum computation and quantum simulation applications?*
2. Are there novel physics beyond the RWA that would significantly contribute to the advancement of quantum technologies with superconducting circuits?

Project goals:

1. Deployment of superinductor-based technology to achieve USCs.
2. Engineer novel qubits with USC physics.
4. Develop applications for superinductors such as photodetectors.

* Recent results in the readout of transmon qubits using resonators clearly point in this direction [Sank2016] in the context of quantum computation and qubit state readout.

Superinductor enabling technology

A superinductor exhibits an impedance exceeding the quantum of impedance, Two strategies exist to build superinductors:

- Josephson junction arrays
- Granular aluminum

\[ Z_I = \hbar/(2e)^2 \sqrt{2E_c/E_I} \]

[Krupko2018] [Maleeva2018]

Novel qubits for USC physics

Key point in SiUCs: Employ superinductors to obtain USCs both in open (a) and closed (b) systems.

Circuit implementations for qubit-waveguide (a) and qubit-resonator (b) systems in the USC regime using superinductors.

Theoretical models will be developed to define new experimental platforms for USC physics for dynamical control and switching.

Applications of superinductor-based circuits

Microwave photodetectors using superinductors

Condensed-matter physics simulation (Kondo)

[Znyman2015] [De Bernardis2018]

The SiUCs consortium

-6 partners: 4 experiment/2 theory.
-33% Women PIs.
-50% Young researchers.
-1 widening country.
-Execution times: 04/20-03/23.
-Total budget: 1.29B€, 70% experiment.