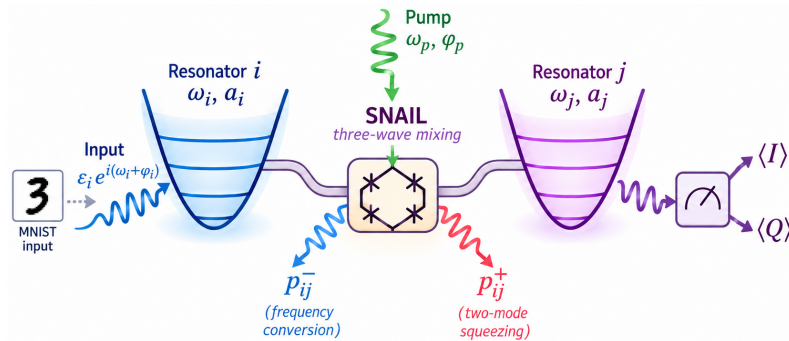


Design and fabrication of superconducting circuits for quantum machine learning

Scientific Context

Quantum neuromorphic computing exploits the dynamics of analog quantum systems to process classical information or quantum states and facilitate their classification through measurements. In our group, we investigate networks of parametrically coupled bosonic modes as a promising architecture for quantum machine learning. Parametric coupling provides a rich set of tunable interactions, while bosonic modes allow access to both continuous-variable observables and discrete photon-number measurements.



We have demonstrated quantum reservoir computing using superconducting circuits and explored the role of quantum coherence in computational performance [1,2]. We have shown that the strengths of simultaneously driven parametric processes, including coherent conversion and two-mode squeezing, can be trained to perform classification tasks such as handwritten-digit recognition [3].

In superconducting circuits, parametric coupling is enabled by the nonlinearity of Josephson junctions. Our first experiments used a Josephson ring modulator (JRM) to implement three-wave mixing. However, higher-order nonlinearities, including self- and cross-Kerr interactions, cause deviations from the ideal Gaussian dynamics used to calculate training gradients. The superconducting nonlinear asymmetric inductive element (SNAIL) offers tunable three-wave mixing while allowing Kerr interactions to be strongly suppressed [4,5].

Work program & skills acquired during internship

The goal of the internship is to replace the JRM with a SNAIL-based three-wave-mixing element coupling two microwave resonators [4–6]. The project will involve electromagnetic simulations, circuit design and optimization, cleanroom fabrication, and cryogenic microwave characterization. Initial measurements will rely on homodyne detection to characterize the resonator modes and parametrically driven interactions, while investigating residual Kerr nonlinearities.

Methods and techniques: finite-element electromagnetic simulations, e-beam and UV lithography, cryogenic microwave measurements and homodyne detection

PhD perspective & work environment

The internship will lay the groundwork for a PhD project aimed at experimentally implementing and training superconducting quantum neural networks. Building on physics-based learning methods recently developed in our team, the PhD will explore how training gradients can be extracted from measurements of the system's response and used to optimize its parametric interactions. The student will work closely with other PhD students in the team developing these learning methods, fostering a strong interaction between hardware development and learning algorithms.

References

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- [3] Dudas et al., *Sci. Rep.* 16, 14997 (2026).
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- [5] Sivak et al., *Phys. Rev. Applied* 11, 054060 (2019).
- [6] Chapman et al., *PRX Quantum* 4, 020355 (2023).

Laboratoire Albert Fert

CNRS · Thales · Université Paris-Saclay
1 avenue Augustin Fresnel, 91767 Palaiseau, France
Contact: [danijela.markovic@cnrs-thales.fr](mailto:danjela.markovic@cnrs-thales.fr)

PhD continuation: YES

Fellowship envisaged: YES