From Al/Al-Ox/Al Josephson Junction Development to Frequency-Multiplexed Microwave SU(1,1) Interferometry

Alessandro Irace[1,2,3], Nicolò Crescini[1,2], Felix Ahrens[1,2], Enrico Bogoni[1,2,3], Giulio Cappelli[1,2], Iacopo Carusotto[4,2], Marcello Faggionato[1,2,3], Paolo Falferi[1,5,2], Andrea Giachero[3,6,7], Benno Margesin[1,2], Renato Mezzena[8,2], Gianluca Rastelli[4,2], Andrea Vinante[5,1,2], Federica Mantegazzini[1,2]

1. Fondazione Bruno Kessler, Via Sommarive 18, 38123 Trento, Italy

2. INFN - TIFPA, Via Sommarive 14, 38123 Trento, Italy

3. University of Milano-Bicocca, Department of Physics, Piazza della Scienza 3, 20126 Milano, Italy

4. Pitaevskii BEC Center, CNR-INO and, University of Trento, Department of Physics, Via Sommarive 14, I-38123 Trento, Italy

5. Istituto di Fotonica e Nanotecnologie IFN-CNR, Via alla Cascata 56, 38123 Trento, Italy

6. INFN - Sezione di Milano-Bicocca, Piazza della Scienza 3, 20126 Milano, Italy

7. Bicocca Quantum Technologies (BiQuTe) Centre, Piazza della Scienza 3, 20126 Milano, Italy

8. University of Trento, Department of Physics, Via Sommarive 14, 38123 Trento, Italy

Abstract: We report Al/Al-Ox/Al Josephson junction development for various devices and applications. As a use case, we demonstrate a frequency-multiplexed SU(1,1) microwave interferometer, achieving promising phase-sensitivity scaling with a novel measurement scheme.

Josephson junctions are one of the fundamental building blocks of superconducting quantum devices, with applications ranging from circuit quantum electrodynamics to precision sensing. At Fondazione Bruno Kessler (FBK), our efforts focus on the development of overlap-style Al/Al-Ox/Al Josephson junctions. This method ensures scalability and high geometrical flexibility, enabling precise critical current tuning for a wide range of applications. Currently, we are further optimizing the fabrication process dedicated to transmon qubits, specifically implementing direct laser lithography and multi-oxidation techniques to enhance the device performance.

This work is the result of a broad collaborative synergy within the NQSTI framework, combining the expertise in design, simulation, microfabrication and cryogenic characterization of FBK, CNR and UniMiB. Within this ecosystem, we report the integration of high-quality junctions into flux-pumped Josephson Parametric Amplifiers (JPAs). At FBK, we have exploited these JPAs to experimentally realize a microwave SU(1,1) interferometer. Unlike conventional SU(2) architectures, this SU(1,1) configuration utilizes the JPA as a source of spontaneous parametric down-conversion to generate entangled microwave beams, achieving high phase-sensitivity scaling. A critical feature of our implementation is its frequency-multiplexing: the entangled beams co-propagate along a single spatial path at two distinct frequencies, significantly reducing susceptibility to environmental phase noise compared to dual-path systems. The resulting interference is analyzed using digital down-conversion for high-fidelity readout. We characterize the quantum nature of the device and discuss its potential for advanced quantum sensing and high-precision measurements.

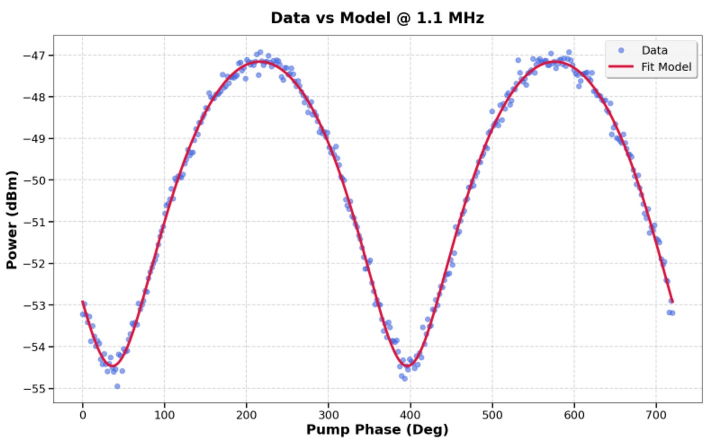

Fig. 1 (blue) Data of the interference pattern given by the frequency based interferometer after digital recombination. (red) Theoretical fit to the data.