Kinetic Inductance Traveling Wave Parametric Amplifiers for Practical Microwave Readout

Andrea Giachero [1,2,3], Logan Howe [4,5], Felix Ahrens[6,7], Jason Austermann [4], Enrico Bogoni[1,6,7], Matteo Borghesi [1,2,3], Pietro Campana [1,2,3], Rodolfo Carobene [1,2,3], Alessandro Cattaneo [1,2,3], Hervè Corti [1,2,3], Nicolò Crescini [6,7], Marcello Faggionato [1,2,6], Paolo Falferi [6,8,7], Marco Faverzani [1,2,3], Elena Ferri [2], Sara Gamba [1,2,3], Andrea Giachero [1,2,3], Marco Gobbo [1,2,3], Johannes Hubmayr [4,5], Alessandro Irace [1,6,7], Danilo Labranca [1,2,3], Benno Margesin [6,7], Federica Mantegazzini [6,7], Renato Mezzena [9,7], Roberto Moretti [1,2,3], Angelo Nucciotti [1,2,3], Luca Origo [1,2,3], Andrea Vinante [8,6,7], Michael Vissers [4,5], Jordan Wheeler [4,5], Joel Ullom [4,5]

1. University of Milano-Bicocca, Department of Physics, Piazza della Scienza 3, 20216 Milano, Italy

2. INFN Sezione di Milano-Bicocca, Piazza della Scienza 3, 20216 Milano, Italy

3. Bicocca Quantum Technologies (BiQuTe) Centre, Piazza della Scienza 3, 20216 Milano, Italy

4. Quantum Sensors Division, National Institute of Standards and Technology, Boulder, CO 80305 USA;

5.Department of Physics, University of Colorado, Boulder, CO 80309 USA

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

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

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

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

Abstract: Superconducting quantum systems and fundamental physics experiments demand amplifiers with large bandwidth and noise to the quantum limit. We present Kinetic Inductance Traveling-Wave Parametric Amplifiers, designed to enhance qubit and detector readout with improved performance.

Ultra-sensitive detection schemes at microwave frequencies are essential for advanced applications, including quantum sensing, quantum computing, and fundamental physics research. In many of these fields, the need to read out large arrays of devices (e.g., qubits, detectors, and cavities) demands amplifiers with large bandwidths and the lowest possible noise levels. While solid-state amplifiers offer exceptional gain, they fall short of reaching the quantum noise limit. Traveling-Wave Parametric Amplifiers (TWPAs), particularly Kinetic Inductance TWPAs (KI-TWPAs), provide a promising alternative [1]. KI-TWPAs are simpler to fabricate than traditional Josephson-junction-based TWPAs and offer additional advantages, such as a high dynamic range, resilience to magnetic fields, and potential operation at higher temperatures (e.g., 4 K [2]).

National research groups, including the Italian Institute of Nuclear Physics (INFN) [3], the Bruno Kessler Foundation (FBK) [4], and the US National Institute of Standards and Technology (NIST) [5], are actively working to advance KI-TWPA performance. Amplifiers fabricated using Niobium Titanium Nitride (NbTiN) have demonstrated impressive results in terms of gain, bandwidth, and compression power. At millikelvin temperatures, KI-TWPAs operating as three-wave-mixing (3WM) amplifiers have achieved significant improvements, including higher gain, broader bandwidth, and noise levels approaching the Standard Quantum Limit (SQL) [6]. These advancements make the devices ideal for reading out multiplexed superconducting qubits and arrays of superconducting detectors.

In this work, we present the design, fabrication, and characterization of KI-TWPAs developed at the University of Milano-Bicocca in collaboration with NIST, FBK, and INFN. We highlight the use of novel materials and innovative layouts. Furthermore, we demonstrate the readout of an array of eight qubits, showing an improvement in the signal-to-noise ratio for qubit state measurements and an increase in fidelity [7]. These results underscore the potential of these devices to influence quantum technologies by enabling rapid, high-fidelity, multiplexed readout of superconducting qubits, thus significantly enhancing the performance of quantum computation, communication, and high-precision sensing.

References

[1] M. Malnou *et al*., "A three-wave mixing kinetic inductance traveling-wave amplifier with near-quantum-limited noise performance", PRX Quantum **2**, 010302 (2021) ;

[2] M. Malnou *et al*., "Performance of a Kinetic Inductance Traveling-Wave Parametric Amplifier at 4 Kelvin: Toward an Alternative to Semiconductor Amplifiers", Phys. Rev. Applied **17**, 044009 (2022);

[3] A.Giachero *et al*., "Detector Array Readout with Traveling Wave Amplifiers", J. Low Temp. Phys. **209,** 3-4, 658-666 (2022);

[4] F. Mantegazzini *et al*., "High kinetic inductance NbTiN films for quantum limited travelling wave parametric amplifiers", Phys. Scripta **98**, 12, 125921 (2023);

[5] A. Giachero *et al.*, “Characterization of NbTiN films with thicknesses below 20 nm for low power kinetic inductance amplifiers”, IEEE Trans. Appl. Supercond. **33**, 5, 1700905 (2023);

[6] A. Giachero *et al.*, “Kinetic inductance traveling wave amplifier designs for practical microwave readout applications”, J. Low Temp. Phys. **215**, 3-4, 152-160 (2024)

[7] “Measurable Improvement in Multi-Qubit Readout Using a Kinetic Inductance Traveling Wave Parametric Amplifier” accepted in IEEE Trans. Appl. Supercond, arXiv:2501.01185 [quant-ph]

Acknowledgements

The work is supported by the Italian National Quantum Science and Technology Institute (PNRR MUR project PE0000023-NQSTI). This work is also supported by the European Union’s project HORIZON-CL4-2023-DIGITAL-EMERGING-01-CNECT Grant Agreement No. 101135868, by European Union’s project H2020-MSCA Grant Agreement No. 101027746, and by the Italian Institute of Nuclear Physics (INFN) within the Technological and Interdisciplinary Research Commission (CSN5).