Advancing Kinetic Inductance Traveling Wave Parametric Amplifiers for Quantum Technologies

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Abstract: We present the current progress towards a rapid simulation and design framework for KI-TWPAs and examples of its use, such as the development of a novel frequency converter-amplifier device.

The scaling of quantum computing systems demands efficient, broadband amplification for multiplexed qubit readout. Kinetic Inductance Traveling Wave Parametric Amplifiers (KI-TWPAs) have emerged as promising candidates [1], offering advantages such as high dynamic range, simplified fabrication, and resilience to magnetic fields compared to Josephson junction-based alternatives. However, the widespread adoption of TWPAs is limited in part due to the necessity of bulky isolators and magnetic circulators in order to minimize reflections from the device, which introduce losses and pose significant integration challenges for larger quantum processors, a problem exacerbated by KI-TWPAs' stronger pump tone requirements.

Here, we present the efforts in the development of a simulation framework capable of greatly reducing KI-TWPAs design iteration time while maintaining accuracy. Our framework combines generalized coupled mode equations for gain prediction with accelerated electromagnetic simulations, enabling rapid prototyping and optimization of device geometries. This advancement significantly shortens the development cycle of new KI-TWPA designs, enabling faster optimization of parameters and validation of prototypes from measurements.

We then show two applications of this framework. First, we validate it by successfully fitting experimental data from a device produced at Fondazione Bruno Kessler (FBK) [2]. Second, we present the first steps towards the design of a new KI-TWPA architecture incorporating both forward amplification and backward isolation, similar to recent achievements with junction-based devices [3] but leveraging the advantages of kinetic inductance. This kinetic inductance-based traveling-wave parametric amplifier and converter promises to eliminate the need for circulators while maintaining the inherent benefits of KI-TWPAs. These advances represent crucial steps toward practical, high-performance amplifiers for large-scale quantum computing systems, offering a path to simplified readout chains that maintain quantum-limited noise performance across broad bandwidths.

References

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