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Experimental demonstrations of nonreciprocal microwave amplification

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Many superconducting quantum circuits rely on microwave photons to measure or couple quantum systems, such as superconducting qubits or micro-mechanical resonators. The ability to process microwave fields with minimal degradation is crucial to the observation of truly quantum behavior. It finds applications in quantum computing, quantum feedback or position measurements. However, to date, there is no system that is able to achieve an ideal measurement of such microwave fields. Indeed, parametric amplifiers, while intrinsically quantum-limited, reflect the amplified signal and back-act onto the system under test, requiring a circulator to break reciprocity and separate incoming and outgoing fields. Unfortunately, conventional ferrite circulators are ultimately incompatible with microwave quantum circuits due to size, loss and magnetic field. In this talk I will describe the development of a new generation of quantum-limited, nonreciprocal microwave amplifiers [1,2]. Using microwave drives, the experimentalist turns on a set of parametric interactions between the modes of a microwave resonant circuit, allowing one to choose in-situ between different modes of operation: frequency conversion, circulation or any combination of reciprocal/nonreciprocal and phase sensitive/preserving amplification. With low insertion loss (<0.5dB), high return loss (<-15dB), high directivity (<-15dB) and high gain (>18dB), these devices are a new tool for quantum measurements. [1] L. Ranzani and J. Aumentado, New J. Phys. 17, 023024 (2015) [2] F. Lecocq., et al, 'Nonreciprocal microwave signal processing with a Field-Programmable Josephson Amplifier', Arxiv (2016)