

Abstract

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Title: Quantum-limited detectors based on superconducting metamaterials

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This dissertation explores quantum-limited detection in superconducting systems, spanning both optical and microwave frequency domains, with an emphasis on the material and theoretical foundations that determine detector performance.

In the microwave regime, we study the operation of traveling-wave parametric amplifiers (TWPAs), which are crucial components in quantum-limited amplification. They are typically analyzed using coupled-mode theory, which assumes perfect impedance matching and neglects reflections. We developed an analytical model that incorporates the effects of reflected waves in nonlinear waveguides, revealing enhanced gain and suppressed nonlinear phase modulation. This extended model was validated on two types of experimental TWPAs: one based on high kinetic inductance superconducting wires and the other employing large arrays of Josephson junctions.

In the infrared regime, we investigate highly disordered ultrathin NbN and NbTiN films—key materials for superconducting nanowire single-photon detectors (SNSPDs). While the optical and superconducting properties of Nb(Ti)N have been widely studied, inconsistencies in their basic electronic parameters remain. We demonstrate that these discrepancies stem from neglecting quantum corrections to conductivity in the infrared range. By incorporating these corrections into a modified Drude-Lorentz model for optical conductivity, we extracted electronic parameters that are consistent with transport and superconducting measurements, offering a refined understanding of charge carrier dynamics in disordered superconductors.

Key words: Quantum-limited detection, parametric amplification, Quantum corrections, Disordered metals