High Saturation-Power Broadband NbTiN Parametric Amplifiers in Reflection and Traveling-Wave Architectures

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1 Introduction

We present the development of high-saturation-power parametric amplifiers based on the nonlinearity of high kinetic-inductance (KI) superconducting materials, offering a promising alternative to conventional Josephson-junction-based designs. Unlike Josephson junctions, which are limited by low critical currents and consequently low saturation powers, KI-based devices enable amplification with up to 30 dB higher input power handling. We explore two approaches for achieving broadband amplification: reflection-type and transmission-type architectures. Both amplifier types utilize a 20-nm NbTiN thin film as the nonlinear element.

Our primary focus is on a reflection-type parametric amplifier, referred to as the KI-IMPA, which employs an innovative impedance-matching network to broaden bandwidth and increase design flexibility. The KI-IMPA architecture incorporates two quarter-wavelength and one half-wavelength coplanar transmission line sections, enabling a wider range of characteristic impedances for the nonlinear resonator than conventional circuits. Using only a 330-fF shunt capacitor, our KI-IMPA demonstrates phase-preserving amplification with a 450-MHz bandwidth and 17-dB gain. The added noise ranges from 0.5 to 1.3 quanta near the center frequency of 8.4 GHz, with a measured saturation power of up to -68 dBm.

We also investigate a kinetic-inductance traveling-wave parametric amplifier (KI-TWPA) employing distributed-coupling resonant phase matching (DCRPM). In this architecture, embedded resonators introduce sharp phase shifts to maintain phase matching between the pump, signal, and idler. Each resonator is coupled to multiple unit cells (in contrast to the one-to-one coupling used in conventional designs), enhancing phase control and reducing the overall device footprint.

Kinetic-inductance-based amplifiers, particularly the reflection-type KIMPA, offer excellent dynamic range, near quantum-limited performance, and compatibility with higher temperatures and magnetic fields. These properties make them ideal candidates for scalable quantum sensing, multiplexed detector readout systems, and second-stage amplifiers to replace high-electron-mobility-transistor amplifiers.