Superconducting Parametric Amplifiers: the Next Big Thing in (Sub)Millimeter-wave Receivers

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Abstract—Superconducting paramps developed for quantum computing have narrow bandwidths, low dynamic range, and operate at sub-Kelvin temperatures. Our collaborators at JPL/Caltech recently demonstrated a microwave Travelling-Wave Kinetic Inductance Parametric (TKIP) amplifier with several GHz of bandwidth, and orders of magnitude larger dynamic range with near quantum-limited noise performance up to an operating temperature of 3K. Similar amplifiers but at higher frequencies up to 1 THz could be designed since the operation principle and physics remain largely unchanged. These qualities make TKIPs suitable candidates for ground-based astronomy with instruments such as ALMA.

In a 2-year study at NRAO we are looking into the feasibility of a high-frequency TKIP demonstration prototype as a front-end replacement for the ALMA band-3 SIS mixer receivers. Our collaborators at Caltech have designed and fabricated a TKIP chip that covers a very wide bandwidth of 55-175 GHz, and we are preparing to test this device at NRAO-CDL. We believe that ultimately the main challenge will be in further optimizing the superconducting thin-film materials to retain their desired properties such as ultra-low loss at temperatures close to 4K.

The enhanced observational capabilities that would be enabled by a RF TKIP amplifier front-end would benefit ALMA science across all bands. For example the Band-3 improved signal-to-noise would be a factor of ~ 5 measured at the receiver input. Including the loss of atmosphere this translates to a doubling of system sensitivity and a factor of ~ 4 increase in array efficiency (speed) enabling the detection of weaker spectral lines and continuum sources and mapping larger fields. The increased sensitivity from the RF front-end relaxes the requirements on IF amplifiers and allows for tradeoff with bandwidth to increase the instantaneous IF bandwidth from the current 4 GHz per sideband per polarization to ~ 10 GHz. For continuum observations, this provides a greater than factor of two increase in efficiency (speed), which combined with the increased RF efficiency would result in a factor of ~ 8 increase in observation efficiency (speed). For spectral observations such a wide bandwidth also enables the detection of various spectral lines simultaneously, removing the need of multiple observations at different LO frequencies to cover the whole band.

These amplifiers are not only interesting for ALMA, but are also very useful for direct detection astronomy (e.g. MKID detectors, TES detectors) for amplifying or multiplexing signals from large focal-plane arrays of photon detectors for space telescopes such as NASA's Origins Space Telescope and X-ray telescopes. Therefore, this development activity is highly synergistic with development of future generations of direct detectors on space and ground platforms.