Cycle 7 NRAO ALMA Development Study Proposal – Technology Development of Quantum-Limited, Ultra-Wideband RF Amplifiers for ALMA: A 65-150 GHz Amplifier Test Case

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ABSTRACT

The ALMA 2030 roadmap recommends the development of receivers with larger bandwidth and better sensitivity for improving observation speed. In this 1 year study, we propose to continue the development of a breakthrough amplifier technology called the Traveling-Wave Kinetic Inductance Parametric (TKIP) amplifier that was invented by our collaborators at Caltech/JPL. These "paramps" are a new type of cryogenic power amplifier applicable in the microwave to THz range (0.001 – 1 THz) that exhibit ultralow noise reaching the fundamental quantum limits set by Heisenberg's uncertainty principle, along with very wide instantaneous bandwidth (an octave or more).

The study of these amplifiers is considered strategic for NRAO's long-term technology program, and their successful development could have a huge impact on the performance of ALMA and other future radio telescopes. In this study, we intend to build upon our progress in developing both microwave (post-downconversion, or IF) and millimeter-wave (pre-downconversion, or RF) paramps during our on-going study from ALMA cycle 5. We designed and fabricated several versions of our IF paramps with improvements in gain, bandwidth, noise, dynamic range, gain ripple, pump power level, and chip footprint. We tested these in our JPL and NRAO/UVA shared testbeds and demonstrated that they can operate at 4 Kelvin while maintaining high gain (~ 15 dB) and wide bandwidth (>6 GHz), although noise has not been tested at 4 K yet. When operated at <1 K, we consistently measured noise within a factor of two of the fundamental quantum limit for our IF paramps. At higher frequencies, we designed and fabricated several RF paramps with a simulated gain of >15 dB over the 65-150 GHz band, and made significant improvements in the fabrication methods. These chips have been mounted and are ready for testing in our W-band testbeds. In cycle 5, significant work was placed in building entirely new laboratory infrastructure at NRAO/UVA for testing both IF and RF paramps in a new testbed that can continuously operate the paramps at temperatures between 10 mK and 5 K. The results from our combined efforts at NRAO/UVA and Caltech/JPL and our new testbed infrastructure have put our team in an excellent position to continue this promising work, which is clearly synergistic with ALMA's roadmap.

The enhanced imaging capabilities that would be enabled by our proposed RF TKIP amplifiers would benefit a wide range of ALMA observations. For example, the Band-3 improved receiver noise performance from a front-end RF TKIP amplifier would increase the array efficiency (speed) by a factor of ~4 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 the IF amplifier and should allow the instantaneous bandwidth to be expanded from 16 GHz to ~ 40 GHz. For continuum observations, this provides a factor of 2.5 increase in imaging efficiency (speed), which combined with the increased RF efficiency would result in a factor of 10 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.

In this 1-year study, we will concentrate our efforts on two fronts: 1) Careful characterization of noise, gain, and dynamic range of our already-fabricated and packaged RF paramps in our W-band testbeds using cryogenic blackbody noise sources, and 2) Developing new materials growth and fabrication techniques at UVML that will allow our team at UVA to fabricate paramp circuits.