Status of ALMA Band 6v2 Receiver Development

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Abstract— **We are developing an upgraded version of the existing 211-275 GHz ALMA Band 6 receiver, referred to as "Band 6v2", which complies with the strategies defined in the ALMA Development Roadmap to 2030 and conforms to the recommendations of the ALMA Front-end & Digitizer Requirements Upgrade Working Group. Our goal is to deliver an improved production-level receiver based on (i) a new Cold Cartridge Assembly (CCA) with increased sensitivity over an expanded 4-16 GHz IF band (4-20 GHz goal) and a modestly expanded 209-281 GHz RF band, and (ii) a new low-noise Warm Cartridge Assembly (WCA). The new Band 6v2 receiver will be backward-compatible with the current Band 6 receiver and will directly replace the existing units installed into the ALMA FE (Front-End) cryostat.**

Keywords—SIS, mixer, sideband separation, LNA, receiver, optics, OMT.

I. INTRODUCTION

In the 20 years since the current ALMA Band 6 receiver was designed there have been significant advances in technology which will allow a fundamentally re-designed receiver to cover a substantially wider IF (Intermediate Frequency) band with lower and flatter receiver noise temperature over an expanded RF (Radio Frequency) band:

• Cryogenic IF amplifiers are now available with lower noise temperature over a significantly expanded band.

• Cryogenic edge-mode IF isolators can be made with low insertion loss spanning more than two octaves, enabling flatter receiver noise temperatures over a much expanded IF band.

• It is now possible to make low leakage-current SIS junctions with higher critical current density, thereby allowing low noise operation over a wider RF band.

• LO (Local Oscillator) sources can now be made with reduced sideband noise, resulting in lower receiver noise temperature.

According to the board-approved ALMA 2030 Development Roadmap [1], the current development priorities are to broaden the receiver IF bandwidth by a factor of two or more and to upgrade the associated electronics and correlator to handle the increased bandwidth, as described by the Wideband Sensitivity Upgrade (WSU) initiative [2].

Driven by the science needs of ALMA, and following a successful outcome of our ALMA project proposal, we are currently developing an upgrade for the existing 211-275 GHz ALMA Band 6 receiver [3] cartridge with a substantially improved second generation version, referred to here as "Band 6v2" [4], which complies with the ALMA Development Roadmap strategy and with the recommendations of the ALMA Front-End & Digitizer Requirements Upgrade Working Group.

Despite its high sensitivity and scientific productivity, Band 6 has some deficiencies that we plan to remedy. Currently, ALMA can handle only 4 GHz of bandwidth per sideband per polarization. The present ALMA Band 6v1 receivers have low noise, of order 4 to 6 times the photon temperature, over ~6-10 GHz IF, but above and below that range they degrade substantially (Fig. 1). As the LO and IF are changed, the SSB receiver noise T_{rx} varies by a factor of 2 or more, typically from a low of ~40 K to ~80 K when LO sideband noise and IF amplifier noise are at their highest. In Band 6, it is particularly desirable to simultaneously observe the $^{12}C^{16}O$, $^{13}C^{16}O$, and $^{12}C^{18}O$ astronomical lines which fall in the frequency range 219-231 GHz. This requires $f_{LO} \approx 225$ GHz, for which the lines of interest fall in the LSB and USB

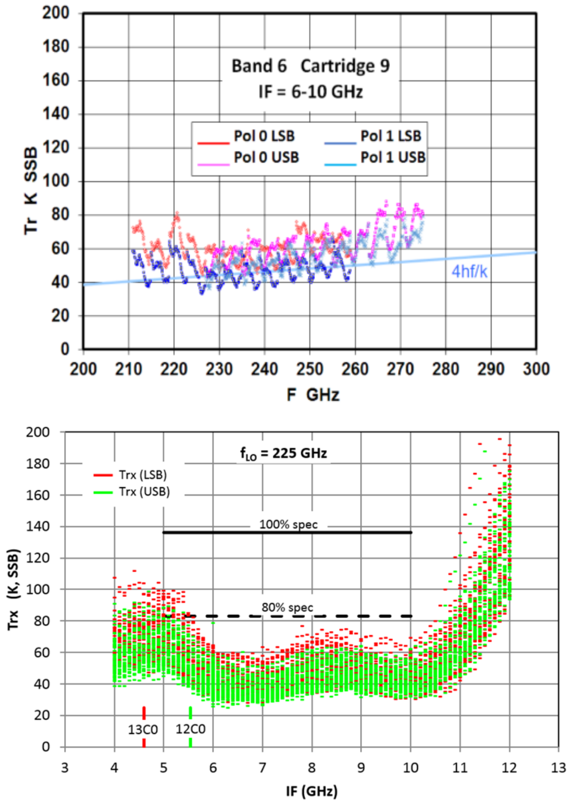

Fig. 1. SSB noise temperatures of Band 6 Cartridge no. 9 versus RF for IF in the range 6-10 GHz (top), and of 80 production Band 6 receivers versus IF for f_{LO}= 225 GHz (bottom).

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and produce IF signals in the range 4.3-5.5 GHz. The bottom panel of Fig. 1 shows the SSB receiver noise temperatures versus IF of 80 production Band 6 receivers with f_{LO} = 225 GHz. It is clear that astronomical lines appearing in the 4.3-5.5 GHz range will be observed with reduced sensitivity.

The interaction between the Band-6 SIS mixer and the IF preamp, which is connected directly to the mixer without an isolator, can cause the cartridge gain to vary across the IF band to an undesirable degree and resulting in many Band 6 mixer-preamplifiers missing gain flatness specifications.

Further, some Band 6 LO modules, which are part of the WCA, have substantial noise in the 4-12 GHz sidebands, at offsets ~4-5 GHz from the carrier frequency. This LO sideband noise contributes to the overall receiver noise temperature for low IF.

Finally, the original polarization efficiency specification of 99.5% could not be met on most of the Band 6 cartridges. A concession was made which relaxed the required polarization efficiency to different percentages over different blocks of frequencies in the 211-275 GHz band.

The upgraded second-generation Band 6 receiver (Band 6v2), will result in several benefits including a reduction in integration time by a factor of ~1.5 to as much as 3 in the worst parts of the current IF (assuming a typical sky temperature), an increase in the IF bandwidth from the present 5.5 GHz per sideband per polarization to at least 12 GHz (4-16 GHz) and potentially to 16 GHz (4-20 GHz), and an increase in RF coverage by 8 GHz, to 209-281 GHz from the present 211-275 GHz.

The four primary goals of the Band 6v2 upgrade are the following:

1) To increase the IF bandwidth from the present 4 GHz per sideband per polarization (across ~6-10 GHz) to 12 GHz per sideband per polarization (minimum 4-16 GHz) or 16 GHz per polarization per sideband (corresponding to our goal of 4-20 GHz IF). While the current ALMA correlator and IF transmission system can only accommodate 4 GHz per sideband per polarization, the new receiver will take advantage of future upgrades of those sub-systems in the framework of the WSU.
2) To expand the usable RF band from the current 211-275 GHz to 209-281 GHz, thereby adding the ability to observe new diagnostic transitions and other lines in Band 6.
3) To improve and flatten the receiver noise performance and IF power density slope across the full IF range.
4) To improve the OMT and optics to achieve lower sidelobes, lower cross-polarization, and easier fabrication.

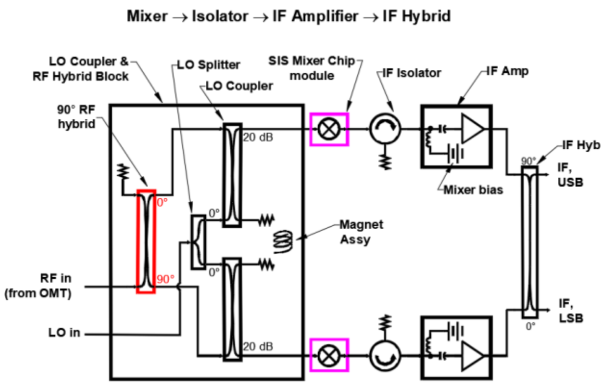

Fig. 2. Schematic of the Sideband Separating (2SB) SIS receiver for Band 6v2 (only one polarization channel is shown). The receiver is based on two DSB SIS mixers cascaded with IF amplifiers preceded by broadband IF isolators.

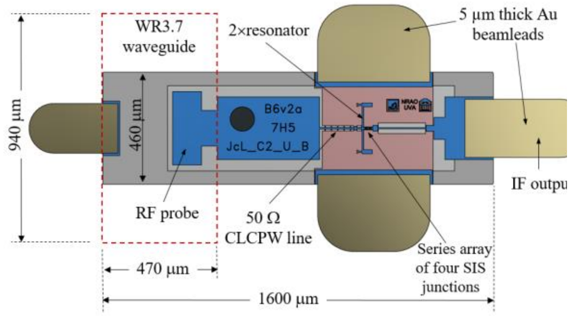

Fig. 3. The layout of the Band 6v2 mixer chip.

The project is exploring several different receiver configurations for the ALMA Band 6v2 sideband separating (2SB) SIS receiver, with improvements to all the major receiver components, including optics, OMT, mixers, IF section and local oscillator. The baseline configuration for one of the two polarizations is shown in Fig. 2. It includes two DSB SIS mixers followed by 4-20 GHz low-loss edge-mode IF isolators from SAO (Smithsonian Astrophysical Observatory) [5], 4-20 GHz IF low noise amplifiers (LNA) from NRAO, and 4-20 GHz IF hybrid from the Yebes Observatory.

In the Band 6v1 SIS mixers, the junctions and associated RF tuning circuits are on an 80-μm-thick quartz substrate. The new Band 6v2 mixer chips (Fig. 3) are fabricated on thin silicon membranes with gold beam leads to provide electrical connections and mechanical support. The drop-in SIS mixer chips, fabricated at UVA IFAB, will utilize 5 μm thick Si with 5 μm thick Au beam leads. The mixer utilizes an array of four Nb/Al-AlOx/Nb SIS junctions in series with target J_C = 6.9 kA/cm^2 (higher than for Band 6v1, which targeted J_C = 5.2 kA/cm^2). Simulations predict flat noise across the RF band. The mixer chips will be easier to package than for Band 6v1.

The individual Band 6v2 mixer chips will be permanently mounted in DSB (Double Side Band) mixer modules which

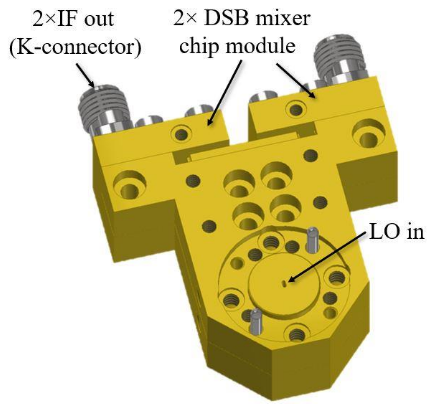

Fig. 4. Preliminary design of Band 6v2 2SB mixer assembly with two DSB mixer chip modules mounted on a passive assembly comprising the RF and LO waveguide circuitry. The RF waveguide input is parallel to the LO waveguide input and is located on the opposite side of the 2SB assembly (not visible).

can be rapidly cooled to determine their I(V) characteristics and DSB mixer properties. This will allow the selection of pairs of well-matched modules for use in sideband-separating mixers. The complete Band 6v2 2SB mixer consists of an E-plane split-block waveguide assembly containing an RF branch-line waveguide hybrid, the LO coupler, and the 4-K image and LO terminations, attached to the two elemental DSB mixer chip modules (Fig. 4). At a later phase of development, a more integrated sideband separating mixer will be considered, after downselection of the receiver architecture.

In Band 6v1, a corrugated feedhorn and a Bøifot junction OMT [6] were adopted, both having a square waveguide (0.94×0.94 mm^2) at their interface flanges. The Band 6v1 OMT incorporates wire pins in the waveguide side-arm, and a thin septum across the square input waveguide whose positioning in the split block is critical to the performance, particularly the polarization properties. A misalignment between the square waveguides of feed and OMT at the interface between the two units can cause the excitation of higher-order spurious modes and generate unwanted cross-polarization. Three alternative waveguide OMT designs that do not use pins or a septum are being considered as replacement for the Bøifot Band 6v1design: a dual-ridge and a reverse-coupler OMT, both designed by NRAO, and an OMT being designed by NAOJ. The NRAO OMT designs are scaled from the W-band models given in [7, 8]. All OMTs adopt circular waveguide inputs (1.29 mm diameter) to match that of the Band 6v2 feedhorn. Unlike the Band 6v1 OMT, the waveguide outputs of the Band 6v2 OMT have E-planes parallel to each other to facilitate integration with the two 2SB mixer assemblies.

By the end of Phase 1 (the current project phase), our goal is to build and demonstrate an improved prototype receiver based on: *a*) a new Cold Cartridge Assembly (CCA) with increased sensitivity over a greatly expanded IF band and modestly expanded RF band; *b*) a new low-noise Warm Cartridge Assembly (WCA) which contains a new LO source with lower AM sideband noise that incorporates a fundamental frequency YIG oscillator operating at twice the frequency of the current one. The receiver optics will also be redesigned. The horn and dual mirror assembly are modified to improve access to the cartridge components for repairs, and an improved low-loss orthomode transducer (OMT) with simpler construction and better reproducibility is being developed.

The improvements from Band 6v2 will unlock discovery space in all three fundamental science areas of ALMA 2030: The Origins of Planets, The Origins of Chemical Complexity, and The Origins of Galaxies.

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