

ALMA Band 5 (163-211 GHz) Sideband Separation Mixer

Bhushan Billade, Victor Belitsky, Alexey Pavolotsky, Igor Lapkin, Jacob Kooi

Abstract— We present the design of ALMA Band 5 sideband separation SIS mixer and experimental results for the double side band mixer and first measurement results 2SB mixer. In this mixer, the LO injection circuitry is integrated on the mixer substrate using a directional coupler, combining microstrip lines with slot-line branches in the ground plane. The isolated port of the LO coupler is terminated by wideband floating elliptical termination. The mixer employs two SIS junctions with junction area of $3 \mu\text{m}^2$ each, in the twin junction configuration, followed by a quarter wave transformer to match the RF probe. 2SB mixer uses two identical but mirrored chips, whereas each DSB mixer has the same end-piece configuration. The 2S mixer has modular design such that DSB mixers are measured independently and then integrated into 2SB simply by placing around the middle piece.

Measurements of the DSB mixer show noise temperature of around 40K over the entire band. 2SB mixer is not fully characterized yet, however, preliminary measurement indicates SSB (un-corrected) noise temperature of 80K.

Index Terms— Millimeter wave mixers, Superconductor-insulator-superconductor mixers, Millimeter wave receivers, Thin film circuits.

I. INTRODUCTION

THE Atacama Large Millimetre/submillimeter Array (ALMA) is a radio interferometer under construction by an international consortia consisting of European countries (ESO), USA, Canada, and Japan. With its more than 60 antennas and reconfigurable baseline up to 10 Km, ALMA will be the most sensitive radio telescope at mm/submm wavelengths.

The work presented here concerns development of one of the bands of ALMA project, ALMA Band 5. ALMA Band 5 will be a dual polarization sideband separating heterodyne receiver covering 163-211 GHz with 4 - 8 GHz IF. For each polarization, Band 5 receiver employs sideband rejection quadrature layout (2SB) based on SIS mixers [3]. The major challenge with Band 5 mixer design is that, there is a very

limited space inside the cartridge. Amongst the other ALMA bands, Band 5 is the lowest frequency band, which uses all cold optics. The optics dimensions put strong constraints on the sizes of all the receiver components and demands a very compact design. Furthermore, the arrangement of the components in the cartridge is such that we have to direct the IF output of the mixers pointing down along the cartridge axis. In such a configuration, the mixer design with a split block technique becomes too big to fit inside the cartridge. We have found that the only possible solution is to use a mixer block configuration with waveguide back piece [2]. This design allows very compact design of the mixer block and also IF output pointing in desirable direction. Furthermore, to avoid extra cables and hence RF losses, all the components in the chain are directly attached to each other with SMA connectors. This design requires a custom made IF hybrid in order to fit the distance between the SMA connectors of the 2SB mixer IF outputs.

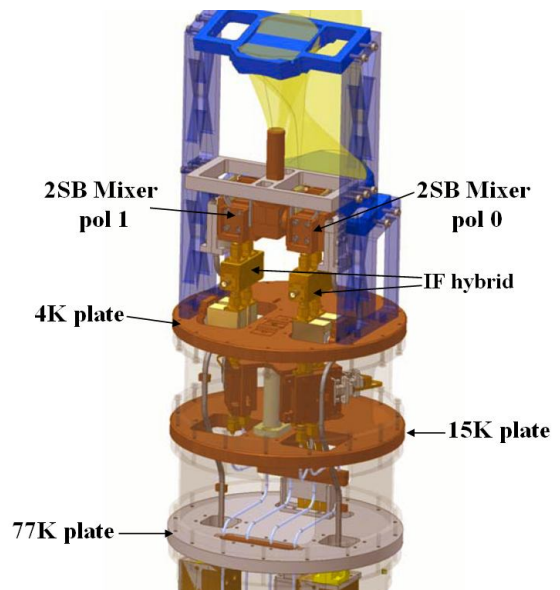


Fig. 1. ALMA Band 5 cartridge layout.

Since there is limited cooling capacity at 4K stage, we can only allow 36mW of heat produced at 4K stage, which does not allow us to integrate the DC bias circuitry into the mixer. In our design, the DC biasing to the mixer is done using a bias box placed on 15K plate. The IF hybrid connected to the combined IF/DC output of the 2SB mixer have an integrated bias-T, and the DC biasing is thus achieved through the output SMA connector of the mixer (Fig. 1).

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Bhushan Billade, Victor Belitsky, Alexey Pavolotsky and Igor Lapkin are with the Group of Advanced Receiver Development (GARD) at Chalmers University of Technology, Gothenburg, Sweden. (phone: 46-31-772 1851; fax: 46-31-772 1801; e-mail: bhushan.billade@chalmers.se).

Jacob Kooi is with the California Institute of Technology, Pasadena, USA.

II. MIXER DESIGN

A. Mixer Chip Design

The chip is fabricated on a 90 μm thick crystalline Z-cut quartz substrate with dimensions 310 μm wide and 2640 μm long. The mixer chip contains along with the SIS junctions most of the DSB components integrated on the same substrate: the chip comprise of an E-plane probes, waveguide-to-microstrip transition, for both the LO and RF, an RF choke at the end of the probe provides virtual ground for the RF/LO signals. We use the same probe with impedance of around 40 Ω for both the LO and RF.

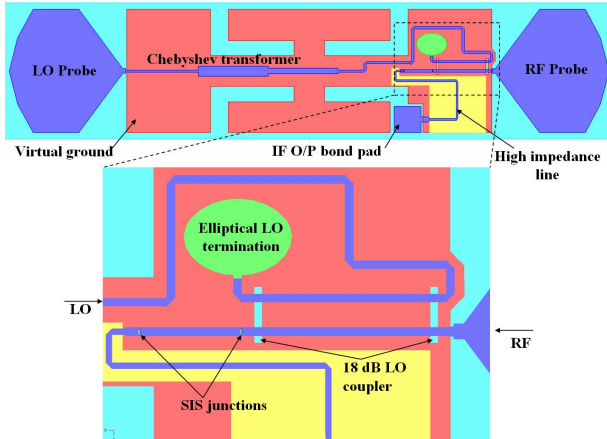


Fig. 2. Mixer chip layout on quartz substrate, containing LO and RF probe, RF choke structure, and IF bond pad. A zoomed view of 18dB LO coupler, elliptical termination and SIS junction.

The RF probe is followed by a LO coupler and two SIS junctions in the twin configuration, and the IF is extracted between the RF and LO waveguides using a high impedance line (Fig. 2). The LO probe is followed by a three stage Chebyshev transformer to match the probe impedance to the LO coupler input, and the reflected signal at the isolated port of LO coupler is terminated using wideband floating elliptical resistive termination [1]. The elliptical termination has the sheet resistance (12 Ω), the same as that of the impedance of the LO coupler input.

The shape of the E-plane probe is optimized for a broad band performance using Agilent Electromagnetic Design System (EMDS), a full 3D EM solver. Probe's real impedance is 42 Ω with $\pm 4\%$ variation across the entire RF band and imaginary impedance of the probe varies between +j5 Ω to -i2 Ω . A hammer type RF choke provides a virtual ground for the RF/LO signal applied between the end of the probe and the choke, which excites microstrip mode between the top conductor layer (LO/RF) and the bottom ground (choke) layer. The thickness of the silicon dioxide layer used for the microstrip line is 350 nanometres. In order to achieve broad band performance from the mixer we use two SIS junctions in twin junction configuration [3, 4] with junctions of size 3 μm^2 each and RnA product of 30. The transmission line length between the two junctions is optimized such that the imaginary part of the twin junction configuration is tuned out. In this configuration the LO coupler serves two purposes: first, it couples the LO signal to RF with weak -18 dB coupling and,

secondly, it transforms the probe impedance from 40 Ω to the input impedance of the twin junction circuitry.

B. Mixer Block Design

The mixer block consists of two parts, a mixer back piece and a middle piece. In the mixer back piece, the mixer chip is glued to the block using wax, a 50 to 15 Ω IF transformer produced on 500 μm thick alumina substrate, the IF signal from the mixer chip is extracted using a bond wire with a single layer capacitor employed at the IF side to compensate for the inductance of the bond wire and the mixer circuitry in order to achieve good IF matching.

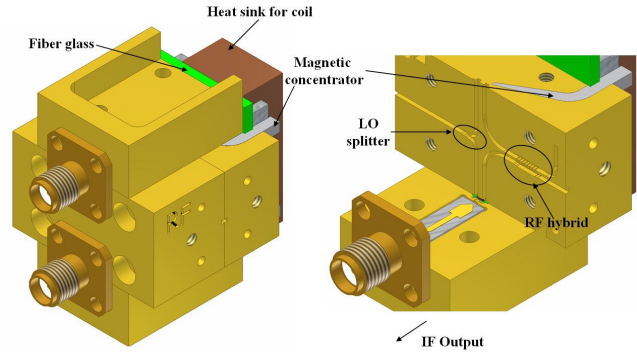


Fig. 3. 2SB Mixer block with two mixer back piece and a middle piece.

The two mixer back pieces should be used in the 2SB configuration and are exactly identical to facilitate production, however the mixer chips used have mirrored layout. The middle piece consists of a 90 $^\circ$ RF hybrid and an in phase LO splitter. In order to suppress the Josephson current, the middle piece also holds magnetic concentrators, and the magnetic coils sit in a copper heat sink. This assembly is connected to the middle piece, using a fibre glass in between, to avoid heat leak from the coils to the mixer block.

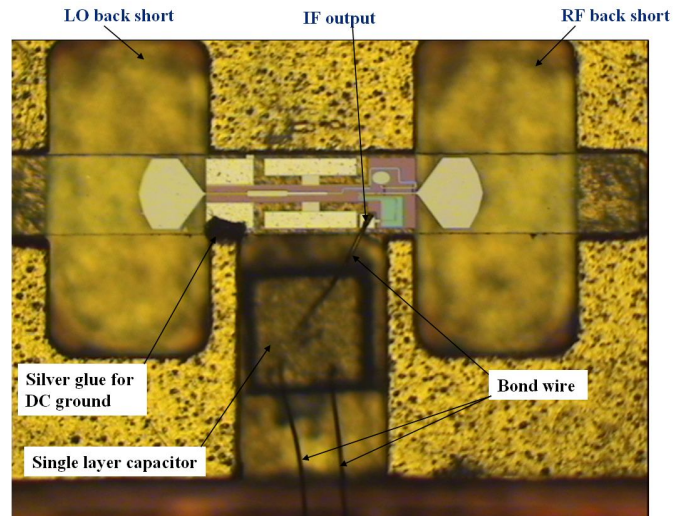


Fig. 4. Mixer back piece with mixer chip.

Fig. 4 shows the picture of the mixer back piece with the chip mounted. In this configuration the mixer chip is installed perpendicular to the direction of E-field in the waveguide. The quartz substrate, used for the chip, extends into the full height for both LO and RF waveguides and even further; this enables a better thermal contact with the mixer block.

III. DSB MEASUREMENT RESULTS

Fig. 5, shows the first experimental results of the DSB mixer, the noise measurements were performed with standard Y factor measurement technique using a hot (293K) and cold (LN2 77K) load placed in front of the test cryostat window. In Fig. 5, we show the noise measurement performed over the entire IF bandwidth with respect to a particular LO frequency. It could be seen from the plot that the noise performance is flat over the IF band for all LO frequencies, except there are peaks at IF for LO frequencies 188 and 192 GHz, and at 197 GHz the Y factor drops abruptly, rising the noise temperature to 170K.

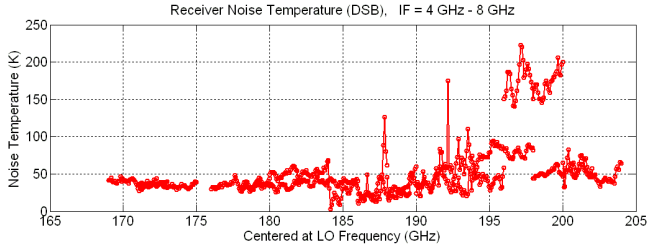


Fig. 5. An un-averaged noise measurement results of DSB mixer.

Fig. 6 displays the noise measurements averaged over the entire bandwidth, measurements shows results with around 35K noise across the band.

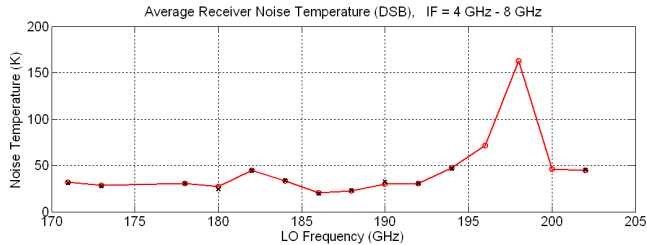


Fig. 6. Noise measurements averaged over the entire IF bandwidth.

After analysis, we realized that the increase in the noise temperature at around 197 GHz is associated with resonance in the mixer back piece. Fig. 7 shows the design of the mixer back piece and the position of the mixer chip. As discussed above, in order to provide better thermal contact between the mixer chip and the block, the mixer chip extends outside the wave guide.

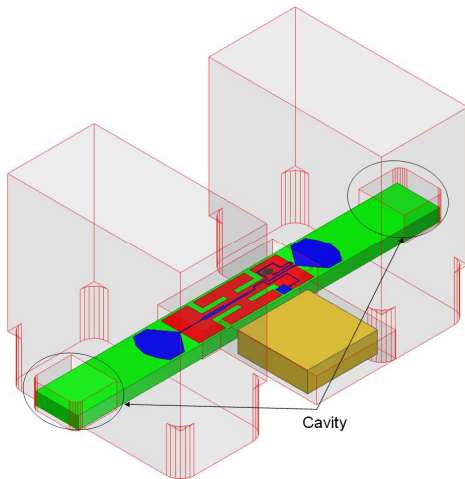


Fig. 7. The original mixer back piece design with deeper substrate channel.

The cavity created above the chip at the two ends causes resonance at around 197 GHz. Since the whole structure is electrically large and thus very complicated to simulate as the whole; we could not see this resonance effect in our simulations, while simulating each component separately. This resonance will also change the behavior of the RF chock structure. Fig. 8 shows the modified mixer back piece, where the top cover height is reduced about the chip, at the two ends. This should move the resonance frequency of the cavity outside the RF band. Fig. 9, shows the noise temperature measurements repeated after reducing the height of the cavity about the chip.

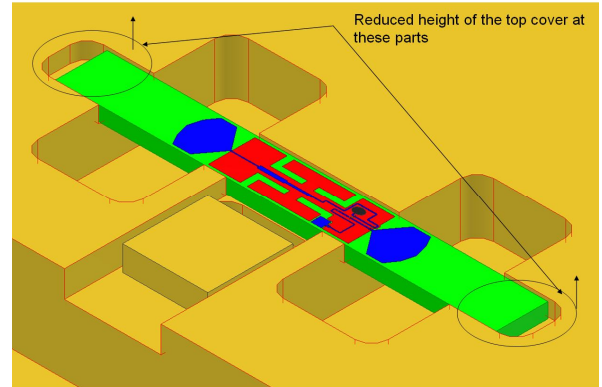


Fig. 8. Modified mixer block with reduced substrate channel height cures "resonances".

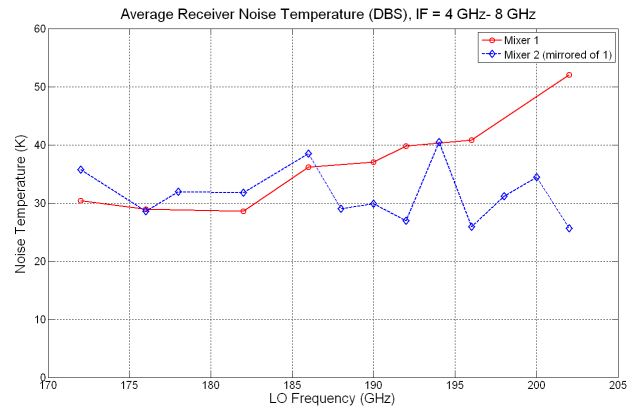


Fig. 9. DSB Noise measurement of two chips used in first 2SB test.

Evidently, the noise peak at 197 GHz is gone and the noise temperature for both the mixers, which are used further for SB measurements, is close to 40K.

IV. IF HYBRID DESIGN

For the reasons discussed in earlier sections and [3], ALMA band 5 design requires a custom made IF hybrid. Since we can not put the SIS bias circuitry at 4K plate, an SIS DC bias-T circuitry is also integrated into the IF hybrid. In order to minimize the RF losses and eliminate series resistance in the SIS junction DC bias circuitry, we use all Niobium superconducting IF hybrid employing Lange-coupler. The pitch between the input SMA connector is pre-defined by the distance between the two output SMA connectors of the 2SB mixer block. The IF hybrid has been fabricated at the in-house facility and uses a 500μm thick Alumina substrate. In order to

avoid possible substrate mode, we use separate substrate of alumina for the Lange coupler itself and for connecting lines: one for the Lange coupler, two for 50 Ohm connecting lines and two for bias-Ts. The interconnection between the different substrates is done using bond wires. Fig. 10, shows the layout of the IF hybrid. DC biasing of the mixer use EMI protection filter bulkhead connectors.

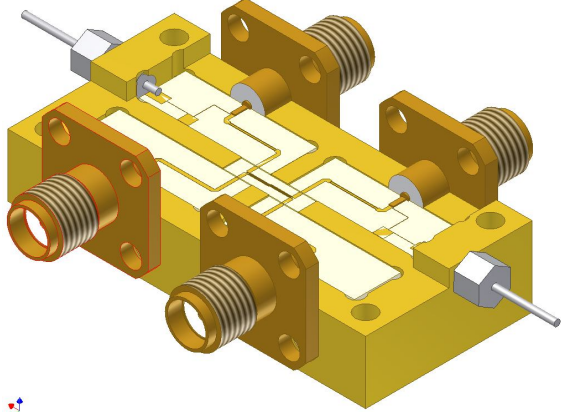


Fig. 10. IF Hybrid with integrated DC bias-Ts.

V. SINGLE SIDEBAND MEASUREMENT

Fig. 11 shows the measurement setup used for 2SB mixer measurements. Mixer output is connected directly to the IF hybrid, followed by an isolator. The noise measurements were performed by Y factor technique while the side band rejection measurements were made by placing a pilot signal at RF employing a comb-generator.

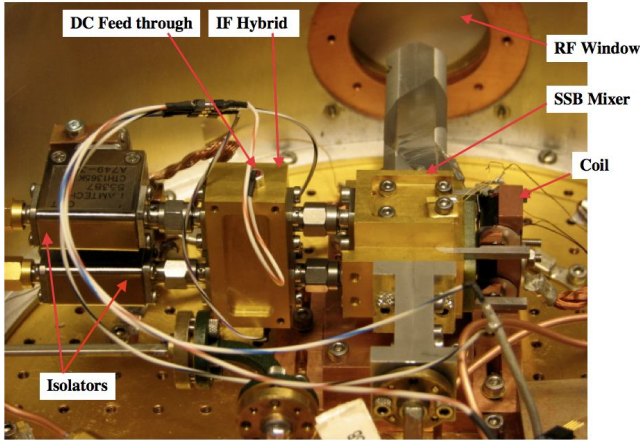


Fig. 11. Single sideband measurement setup.

In Fig. 12, the current voltage characteristics (IVCs) of the two mixers are presented after the suppression of super current and used in the 2SB measurements. Both the mixers have very symmetric and identical IV characteristics. However, it is noticeable difference in the noise performance of the mixers, especially at the higher frequencies of the RF band. While performing measurements of the 2SB configuration, we have noticed that the mixers susceptibility to the LO pumping is different despite the high similarity of the IVCs. We are investigating a possible reason for such behavior, which clearly causes degradation of the 2SB noise temperature as compared to the expected from DSB mixer tests.

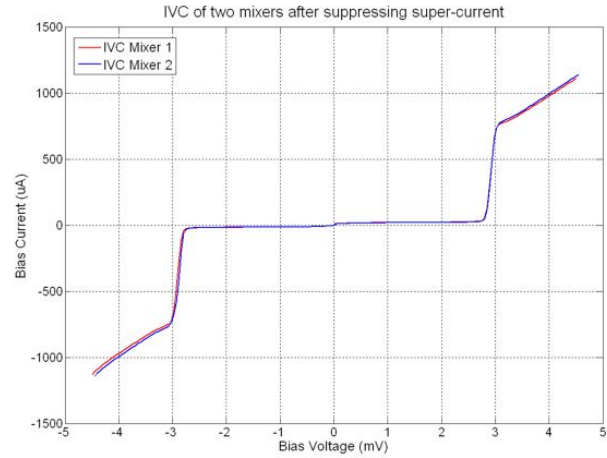


Fig. 12. IVC of two mixers used in 2SB mixer is highly identical that should provide required symmetry of the quadrature layout.

Fig. 13 shows the first noise measurement results of the single sideband mixer. The 2SB noise temperature is between 85K and 170K. This is far more than what we expected from DSB measurements. However, this is the first 2SB noise measurement and analysis of the results is in process.

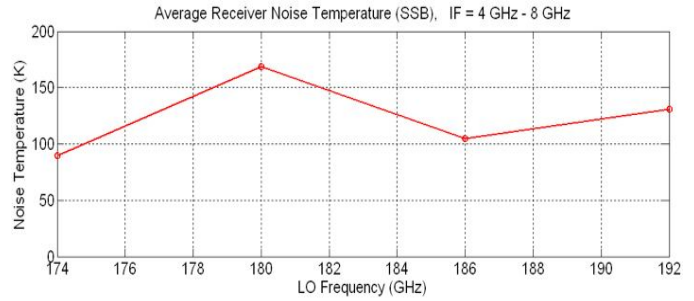


Fig. 13. SSB Noise temperature measurement

VI. CONCLUSIONS

In this paper, we present the design of ALMA Band-5 (163-211 GHz) mixer, measurement results of DSB mixer and first measurement results of the 2SB mixer. The mixer design uses on-chip LO injection circuitry employing a -18 dB microstrip-slot-line directional coupler and a high performance elliptical termination for the isolated port of the LO coupler. The DSB measurement of ALMA Band 5 mixer shows promising results with 35K to 40K noise temperature, across the band. The SSB measurements show noise temperature between 85K and 170K.

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