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

Bhushan Billade[1,*], Victor Belitsky[1], Alexey Pavolotsky[1], Igor Lapkin[1], Raquel Monje[1], Vessen Vassilev[1], Jacob Kooi[2]

[1]*Group for Advanced Receiver Development, Chalmers University of Technology, Gothenburg, SE 412 96, Sweden*

[2]*California Institute of Technology, Pasadena, USA*

`* Contact: Bhushan.Billade@chalmers.se, phone +46-31-772 1851`

Abstract— **We present the design of ALMA Band 5 sideband separation mixer based on Niobium superconducting SIS junctions and first experimental results for the double side band mixer. In this mixer the LO injection circuitry is integrated on the mixer substrate using a microstrip line directional coupler with slot-line branches in the ground plane. The isolated port of the LO coupler is terminated by a wideband floating elliptical termination. The mixer employs two SIS junctions with junction area of 3 μm^2 each, in twin junction configuration, followed by a quarter wave transformer to couple it to the RF probe.**

First measurements of the DSB mixer show promising results with noise temperature around 35K over the entire band.

I. INTRODUCTION

The Atacama Large Millimetre 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 50 antennas and reconfigurable baseline up to 10 Km, ALMA will be the most sensitive radio telescope at mm/submm wavelengths in the world.

The work presented here concerns development of one of the bands of ALMA project. 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. 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 demand a very compact design. Furthermore, the arrangement of components in the cartridge is such that the output of mixer should be directed pointing down along the cartridge axis. In such a configuration, the mixer design with a spilt block technique becomes too big to fit inside the cartridge; 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.

Since there is limited cooling capacity at 4K stage, we can only allow 35mW heat produced at this 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 at the end of the 2SB mixer will have an integrated bias-T, and the DC biasing will be achieved through the output SMA connector of the mixer (figure 1).

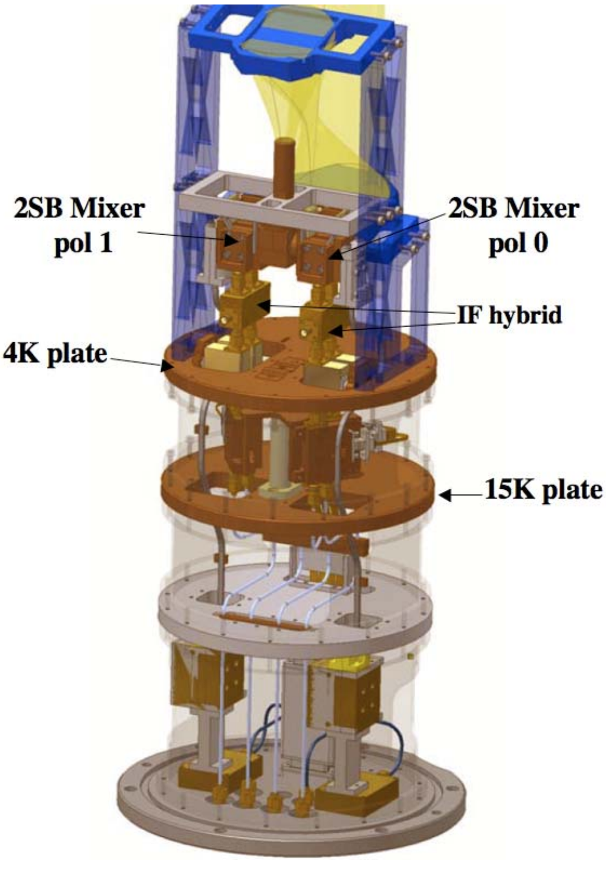

Fig. 1 ALMA Band 5 cartridge layout.

II. MIXER DESIGN

A. *Mixer Chip Design*

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

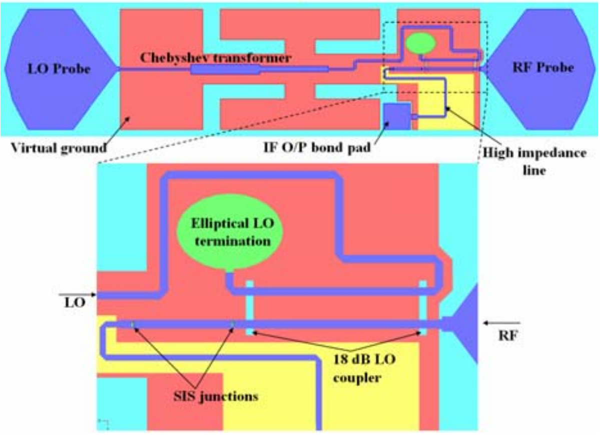

Fig. 12 Mixer chip layout on quartz substrate, containing LO and RF probe, RF choke structure, and IF bond pad. A zoomed vied of 18dB LO coupler, elliptical termination and SIS junction.

The RF probe is followed by a LO coupler and two SIS junctions in twin configuration, and the IF is extracted between the RF and LO waveguides using a high impedance line (Figure 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) same as that of the impedance of the LO coupler.

The shape of the E-plane probe is optimised for broadband performance using Electromagnetic Design System (EMDS), a full 3D EM solver. Probe's real impedance is 42Ω with ± 4% variation across the entire RF band and imaginary impedance of the probe varies between +j5 Ω to –j2 Ω. A hammer type RF choke provides a virtual ground for the RF/LO signal applied between the ends 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 broadband performance from the mixer we use two SIS junctions in twin junction configuration [3, 4] with junction size 3 µm² each and RnA product of 30. The distance between the two junctions is optimised using transmission line 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. The mixer back piece holds mixer chip glued to the block using wax, a 50 to 15 Ω IF transformer produced on a 500µm thick alumina substrate, the IF output from the mixer chip is extracted using a bond wire. A single layer capacitor is used at the IF side to compensate for the inductance of the bond wire and to achieve good IF matching.

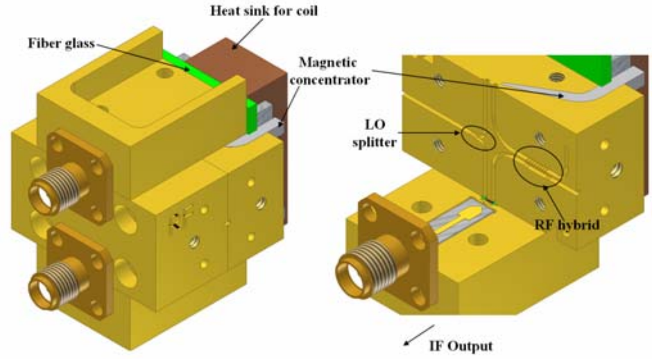

Fig. 13 2SB Mixer block with two mixer back piece and a middle piece.

The two mixer back pieces used in the 2SB configuration are exactly identical, however the mixer chips used have mirrored layout. The middle piece consists of a 90^0 RF hybrid and an in-phase LO splitter. In order to suppress the Josephson current, the middle piece also holds magnetic concentrators. The magnetic coils used sit in a copper heat sink. This assembly is connected to the middle piece using fibreglass in between to avoid heat leak from the coils to the mixer block.

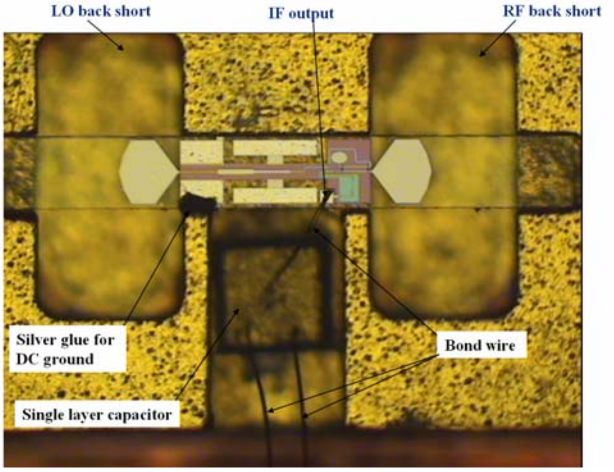

Fig. 4 Mixer back piece with mixer chip.

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

III. DSB MEASUREMENT RESULTS

Figure 5 shows the first experimental results of the DSB mixer, the noise measurements were performed with standard Y factor measurement technique using a hot (293 K) and cold (LN_2 77 K) load placed in front of the test cryostat window.

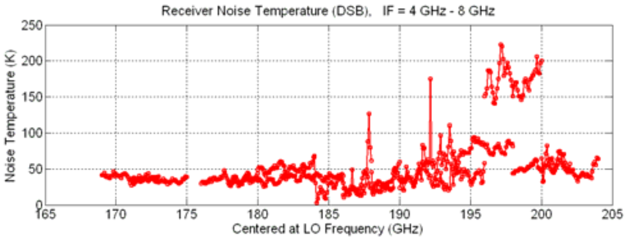

Fig. 5 An un-averaged noise measurement results of DSB mixer.

Figure 5, shows the un-averaged noise measurement performed over the entire IF bandwidth with respect to a particular LO frequency. It can be seen from the plot that the noise performance is flat over the IF band for all LO frequencies, except there are few strange 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.

Figure 6 shows the noise measurements averaged over the entire bandwidth, with noise temperature around 35K across the band.

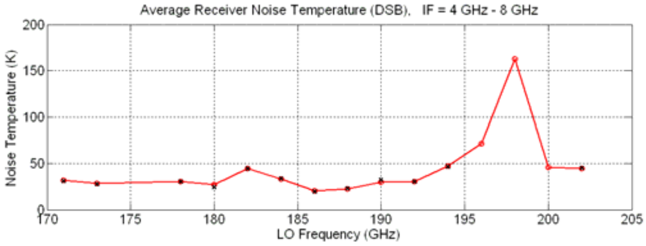

Fig.6 Noise measurements averaged over the entire IF bandwidth.

An increase in the noise performance around 197 GHz is associated with the way chip was grounded. In this measurement setup we used a silver paint to DC ground the chip instead of planned bondwire ground around the hammer structure of the choke. We plan further experiments to investigate the effect of the DC grounding position on the choke performance. Another possibility is that increased noise comes from the LO source and at this point neither of the reasons could be ruled out completely. [1] .

Both these problems need careful investigation. Furthermore, we need to check whether this strange behaviour comes from the mixer chip tuning structure or the embedding circuitry itself.

CONCLUSIONS

In this paper we present the design and first measurement results of a DSB SIS mixer for ALMA Band 5 (163-211 GHz). 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 first measurement of ALMA Band 5 DSB mixer shows promising results with 35K noise temperature across the band. The deviation in the noise performance at LO frequency 197 GHz need investigation.

ACKNOWLEDGMENT

Authors would like to thank Dr. Denis Meledin, Dr. Vincent Desmaris, and Dimitar Dochev for their help and useful discussion. We would like to thank our machining expert, Sven-Erik Ferm, for his useful tips and comments for designing the mixer block. Also, authors would like to thank Doug Henke for useful discussion and his help during the design and measurements. This project is funded by EU FP6 construct 515906 ALMA Enhancement.

REFERENCES

[1] “High quality micro-strip termination for MMIC and millimeter - wave applications”, Raquel Monje, V. Vassilev, A. Pavolotsky, V. Belitsky, IEEE MTT-S international microwave symposium, June 2005.

[2] “SIS Mixer for 385-500 GHz with on chip LO injection”, Raquel Monje, Victor Belitsky, Christophe Risacher, Vessen Vassilev and Alexey Pavolotsky, Proceedings of 18th International Symposium on Space Terahertz Technology, March 2007.

[3] Belitsky V. , Tarasov M.A., "SIS Junction Reactance Complete Compensation", IEEE Trans. on Magnetic, 1991, MAG- 27, v. 2, pt. 4, pp. 2638-2641.

[4] Belitsky V. , Jacobsson S.W., Filippenko L.V., Kovtonjuk S.A., Koshelets V.P., Kollberg E.L., "0.5 THz SIS Receiver with Twin Junctions Tuning Circuit., " Proc. 4th Space Terahertz Technology Conference, p.538, March 30 - April 1, 1993, Los Angeles, USA.

[5] “Quantum detection at millimeter wavelengths”, John Tucker and Marc Feldman, review of Modern Physics vol. 57, No. 4, Oct 1985.

[6] Improving accuracy of superconducting microstrip line modeling at millimeter and sub-millimeter waves, Victor Belitsky, C. Risacher, M. Pantaleev, V. Vassilev, ALMA memo no. 533, Oct 2005.

[7] “A full height waveguide to thin film micro-strip transition with exceptional RF bandwidth and coupling efficiency”, J. Kooi, G. Chattopadhyay, S. Withington, F. Rice, J. Zmuidzinas, C. Walker, and G. Yassin, IR & MM waves, vol. 24, no. 3, 2003.

[8] “Surface impedance of superconductors and normal conductors in EM simulators”, A. R. Kerr, MMA memo no. 245, Jan 1999