A Wideband RF and Wideband IF DSB SIS Mixer

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***Abstract*— The ALMA 2030 Roadmap document calls for a new generation of receivers for ALMA. Such Wideband Sensitivity Upgrade, WSU, aims to improve the existing receiver bands of ALMA with prospectively 4-times wider IF bandwidth and possibly a wider RF bandwidth. In order to explore a possibility to make wideband RF and simultaneously wideband IF receiver, we constructed and built a DSB SIS mixer covering the RF band 210-380 GHz. The mixer exhibits a 4 – 20 GHz IF band and produces non-corrected nose temperature between 3hf/k and 4 hf/k averaged over the IF band.**

***Index Terms*— ALMA receivers, wideband, SIS DSB mixer**

I. INTRODUCTION

The ALMA observatory is the most powerful instrument for modern radio astronomy and has been operational for over 10 years, while the original fundamental science goals of ALMA have been essentially achieved [1]. A new generation of receivers is needed to “significantly expand ALMA’s capabilities and enable it to produce even more exciting science in the coming decades” [1]. The frequency band between 200 and 400 GHz is suggested as the most scientifically significant for upgrading with such new receivers.

Earlier works on wideband receivers have demonstrated a possibility to achieve a twice wider IF bandwidth, e.g. [2] as compared to the counter-part of ALMA. In [3], a wideband RF SIS mixer covering RF band width of 275 – 500 GHz have been presented. In this paper, we present our work on a DSB SIS mixer that covers the RF band 210 – 380 GHz, fractional band 56%, with IF bandwidth 4 - 20 GHz.

II. SIS MIXER DESIGN

The SIS mixer design takes advantage of an improved process for SIS junction fabrication [4] yielding high quality superconducting tunnel junctions with AlN tunnel barrier. Besides featuring a lower specific capacitance as compared to the tunnel junctions using AlOx as the tunnel barrier, this type of junctions also allows the fabrication of higher current density SIS junctions (or low RnA product, where Rn - junction normal resistance and A is junction area) without compromising the junction quality. Fig. 1 illustrates improvements in the specific SIS junction capacitance vs. RnA product, where Rn is SIS junction normal resistance and A is junction area in square micrometers.

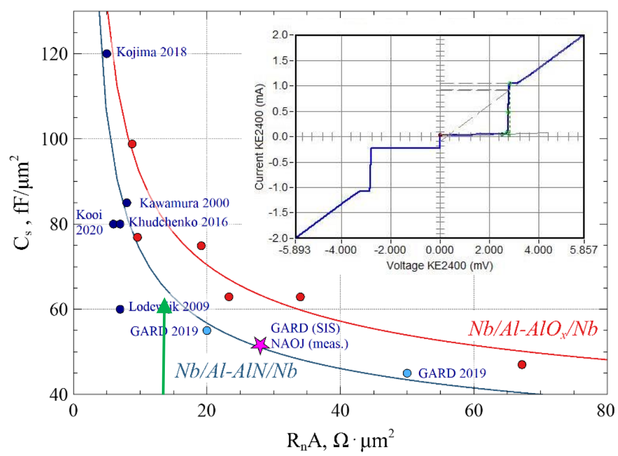

Fig. 1. Diagram connecting the specific capacitance per unit of area of SIS junctions with AlxOy and AlN tunnel barriers with product of its normal resistance, Rn, and area, A. The green arrow/dot shows the choice of the RnA for the SIS junctions used for the mixer in the current project. The junction area is 2 µm^2. The insert shows IVC of the fabricated SIS junctions (twin configuration, the DC measurements performed in the “current-source” mode) with measured Rj/Rn~30.

The designed mixer chip has twin-junction tuning circuitry [5] complemented with 2-step transformer connected to a broadband E-probe. The virtual ground employs hammer-type low-pass filter planar structure. Similar hammer-type filters structure is used to preclude leaking the RF into the IF/DC circuitry. The mixer block, Fig. 2, was milled from Tellurium copper, the waveguide dimensions are 380x760 µm.

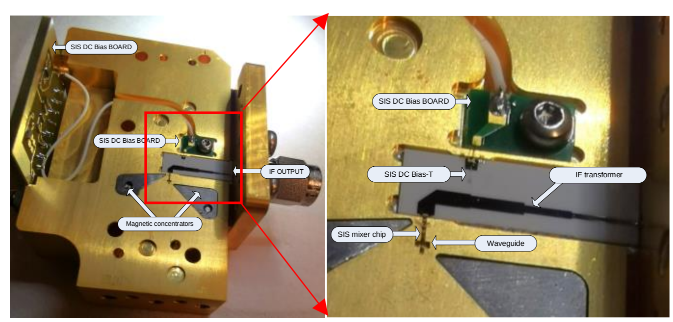

Fig. 2. The mixer block, Fig. 2, was milled from Tellurium copper, the waveguide dimensions are 380x760 µm. The IF circuitry includes 50-to-20 Ohm 3-step transformer with integrated DC bias-T. The latter uses spiral inductor and high-impedance microstrip line with termination capacitor to effectively isolate IF/DC. The entire IF circuitry is fabricated on alumina substrate with Nb sputtered lines.

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effectively isolate IF/DC. The entire IF circuitry is fabricated on alumina substrate with Nb sputtered lines. DC blocking capacitors are fabricated together with the IF circuitry and use SiO_2 insulator of about 300 nm thick. All DC and IF interconnections between the SIS mixer chip, IF board and DC bias circuitry was performed via wire-bonding with 16 µm diameter gold wires.

III. SIS Mixer Measurements and Performance

The measurements of the mixer were performed in a test cryostat using cold optics identical to [2], while for the ALMA Band 6 frequencies, the corrugated horn was replaced with a diagonal horn while using the same cold mirrors, Fig. 3. The LO injection was performed via 30 µm thick Mylar beam splitter at room temperature.

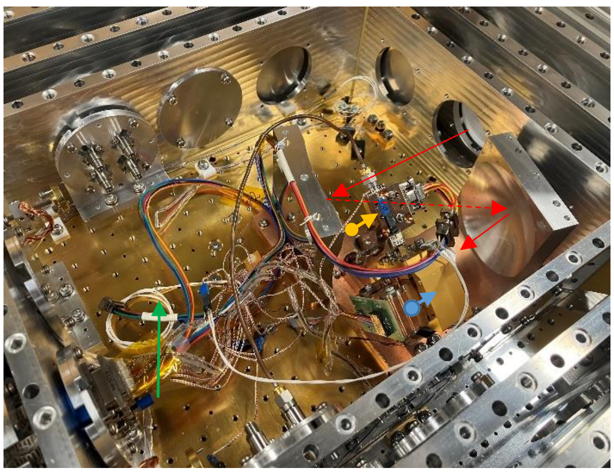

Fig. 3. Photo of the test cryostat interior. The red arrows show the RF input beam path. The blue dot indicates the mixer block position while the orange dot points to the cold 4-20 GHz IF amplifier, produced by Yebes [6], that directly attached to the mixer IF output. No IF isolator was used.

At the time of measurements, we had to use 4-18 GHz room temperature amplifier that have noticeable degradation right after 18 GHz with some noisy feature around 18.4 GHz, which affects the measured noise temperature. Fig. 4 displays the measured noise temperature at 4-20 GHz IF band at LO frequency 285 GHz and have quite typical behavior for all measured LO frequencies. The hot and cold temperature IF traces also presented in the

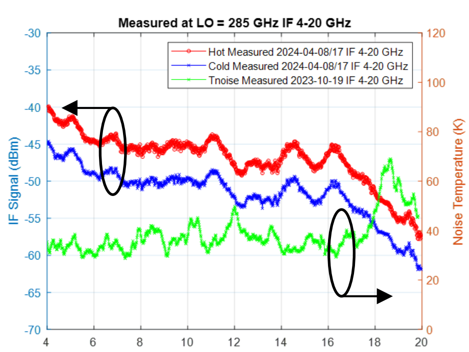

Fig. 4. Measured hot/cold traces and the non-corrected noise temperature for LO frequency 285 GHz, DSB SIS mixer, IF 4-20 GHz. The room temperature IF amplifier specified for 4-18 GHz band is the likely the reason of higher noise above 18 GHz.

Fig. 4 shows a slope about -20 dB across 3-20 GHz IF band that is very repeatable for all LO frequencies and thus could be equalized. Our measurements show that about 11,5 dB of the slope are connected to the RF insertion loss in the coaxial cables connecting cryogenic LNA, room temperature LNA and a spectrum analyzer used to characterize the receiver. The non-corrected measured noise temperature vs. LO frequency is presented in Fig. 5. It should be noted that for LO frequencies at ALMA Band 6, we used quartz window with Teflon matching layer produced by QMC and a diagonal horn while for LO frequencies in the ALMA Band 7, an HDPE plastic window with anti-reflection ridges were fabricated and used during the measurements with the corrugated horn from the SEPIA345 receiver [2].

The noise budget calculations that considers RF loss in the beam splitter, input cryostat window and 110 K and 15 K infrared filters predicts the noise temperature at the input of the cold optics in the range 14-17 K for the IF 4-20 GHz. Fig. 5 displays the noise temperature of the receiver measured at the input of the beam-splitter and averaged over the IF bandwidth.

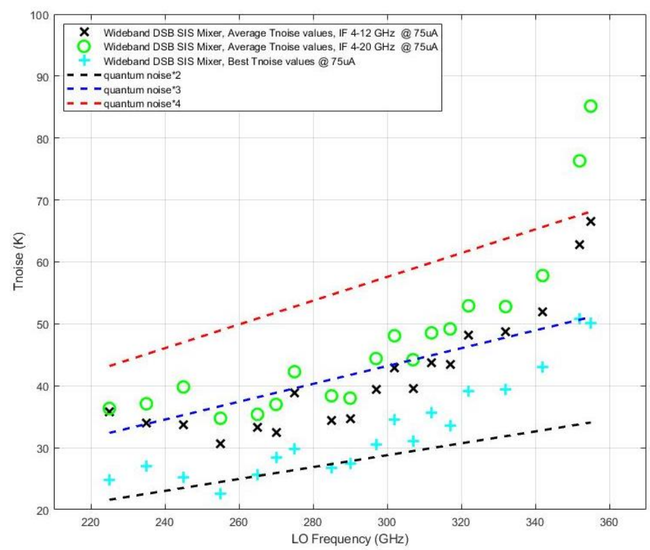

Fig. 5. Measured non-corrected DSB receiver noise temperature vs. LO frequency. Cyan crosses show the best noise temperature obtained for particular LO frequency. The black crosses show the receiver noise temperature averaged over the IF band 4 – 12 GHz and green circles indicate the receiver noise temperature averaged over the IF band 4 – 20 GHz. Red, blue and black dashed lines show the level of 4-, 3- and 2-times quantum noise respectively.

IV. Discussion

The measured noise temperature of the mixer increase follows in general the linear dependence vs. LO frequency. The best detected noise temperatures are close to two times the quantum noise, hf/k, while the averaged over the IF band noise temperatures are between times 3 and 4 the quantum noise. However, above 340 GHz LO, the performance of the mixer started to be influenced by slightly detuned SIS mixer (SIS junctions RnA=17 instead of the designed value RnA=14). At this frequency the 30 µm thick Mylar beam-splitter becomes close to 1/8 the wavelength, and introduces additional factor of the RF loss and contributes to the increase of the noise temperature.

Interestingly, we observed nearly constant difference between the ultimately best measured noise temperature (still averaged over 100 MHz band) and the averaged over the IF band noise temperature, Fig. 5. The best noise temperature points in the plot, Fig. 5, follow the same pattern as the noise temperature averaged over the IF band, and thus should be considered as part of real mixer performance. Suggesting that at the point of detecting the lowest noise temperature, the mixer exhibits high conversion gain, the difference between the best and the averaged over the IF 4-12 GHz band noise temperatures reveals the contribution of the IF part of the receiver, and is about ~7 - 8 K. This is consistent with the noise temperature of the IF amplifier ~4 K providing the averaged gain (of the mixer + optics loss + LO injection beam-splitter loss) in total is about -3 dB.

As mentioned above, the noise budget predicts 14 - 17 K noise temperature at the input of the cold optics. If we speculate that the 2SB mixer integrated in an ALMA cartridge will have ~2.8 times higher noise temperature, this based on our ALMA Band 5 experience, we end up with 39 – 48 K noise temperature that should fulfill ALMA specifications for both Band 6 and Band 7 [7]. Planned replacement of the room temperature IF amplifier that will perform over the entire IF band 4 - 20 GHz should improve the IF performance even above 18 GHz.

Acknowledgements

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