The ALMA band 7 mixer

D. Maier, A. Barbier, B. Lazareff, and K. F. Schuster

***Abstract*—A sideband separating SIS mixer with a 4–8 GHz IF band and covering the RF frequency range of 275 to 373 GHz has been developed and characterized for integration into the ALMA band 7 cartridge. The obtained results regarding noise as well as image rejection are well within the ALMA specifications. SSB noise temperatures as low as 55 K could be achieved for the lowest frequencies and over 98% of the frequency range the noise is less than 100 K. Image rejection is better than 10 dB.**

***Index Terms*—sideband separating mixer, SIS mixer**

I. Introduction

THE MIXER intended for integration into the ALMA band 7 cartridge has to fulfill a multitude of specifications. First of all the RF band has to cover frequencies between 275 and 373 GHz. For a 2SB mixer as chosen for band 7 the IF bandwidth has to be 4 GHz per sideband. The SSB noise limit has been set to 133 K for 80% of the RF band and 198 K for the rest of the band. Finally, the image rejection has to be at least 10 dB.

With the prospect of producing all 128 mixer units for the 64 antennas and thus bearing reproducibility and reliability in mind, a modular approach has been chosen based on single-ended double sideband mixers and waveguide and IF hybrids. This allows testing of the different parts prior to integration and in particular choosing two similar DSB mixers to achieve an optimum result for the 2SB mixer.

II. 2SB Mixer Assembly

A schematic view of a sideband separating mixer is shown in Fig. 1. The two DSB mixer units are connected at their inputs and outputs to quadrature hybrids. The LO signal is split and applied in-phase to the two mixers through –16 dB injection couplers. Since upper and lower sideband signals undergo different phase shifts, they appear separately at the two outputs of the IF quadrature hybrid [1].

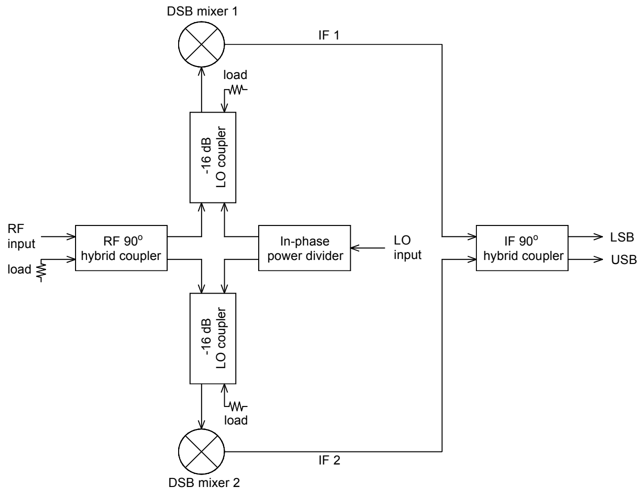

Fig. 1. Schematic view of a sideband separating mixer.

In order to allow testing of the different parts prior to integration, we have chosen a modular approach for our 2SB mixer. Each 2SB mixer assembly consists of a waveguide coupler combining the RF 90° hybrid coupler, the two –16 dB LO couplers and the in-phase power divider in one E-plane split-block [2], two separate DSB mixer units, and a commercially available IF 90° hybrid coupler. A photo of such a 2SB mixer assembly is shown in Fig. 2. The two DSB mixer units as well as the feedhorn are mounted onto the waveguide coupler. In order to allow the suppression of Josephson currents, each mixer has a magnetic yoke assembly attached to it (only one is shown in the photo). The IF outputs of the mixers are connected via semirigid cables to the inputs of the IF quadrature coupler.

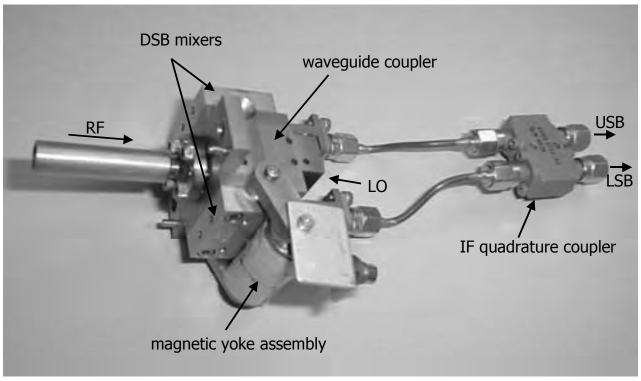

Fig. 2. 2SB mixer assembly with feedhorn, waveguide coupler, two DSB mixer units, and IF quadrature hybrid.

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III. DSB MIXER

A. RF design

The essential part of the mixer is a superconductor-insulator-superconductor (SIS) tunnel junction, which is deposited together with a superconducting circuit onto a quartz substrate. This circuit comprises the antenna providing a full-height waveguide to suspended microstrip transition, the RF choke and the actual tuning circuit whose role is compensation of the junction capacitance and matching to the antenna impedance. Fig. 3 shows the layout of one individual mixer chip with a size of $0.25 \times 2 \times 0.08$ mm^3. These devices are fabricated by IRAM's SIS group. The Nb-Al/AlO_x-Nb tunnel junction has an area of 1 μm^2 and is made by e-beam lithography [3].

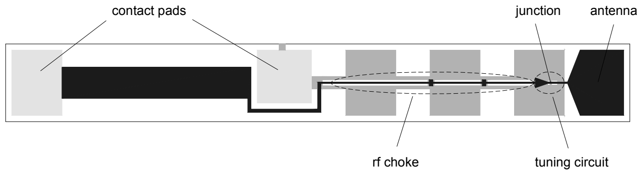

Fig. 3. Layout of the mixer chip.

The mixer chip is placed in a channel perpendicular to the waveguide axis and stretches only partly across the waveguide as can be seen in Fig. 4. The full-height waveguide to microstrip transition is provided by an antenna structure that has been optimized using CST Microwave Studio [4]. The resulting antenna impedance is almost constant over the operating frequency range (see Fig. 5).

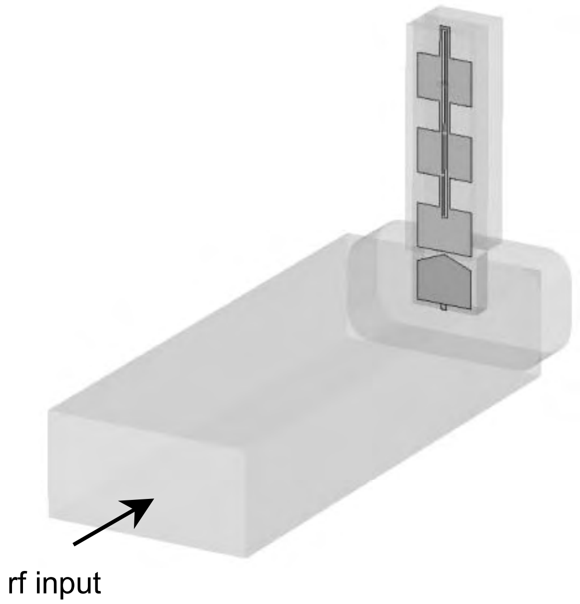

Fig. 4. Full-height waveguide to mircostrip transition.

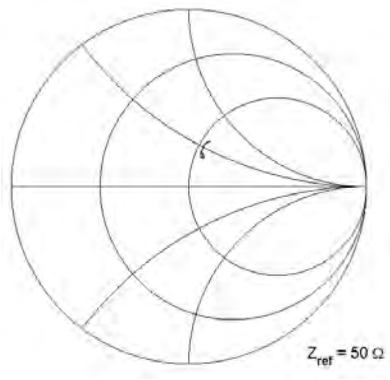

Fig. 5. Antenna driving point impedances for frequencies between 275 and 370 GHz.

A superconducting tuning circuit has been developed and optimized using Sonnet [5] and ADS [6]. Fig. 6 shows a photo of a fabricated mixer chip with a close-up of the tuning structure. The equivalent circuit is shown in Fig. 7.

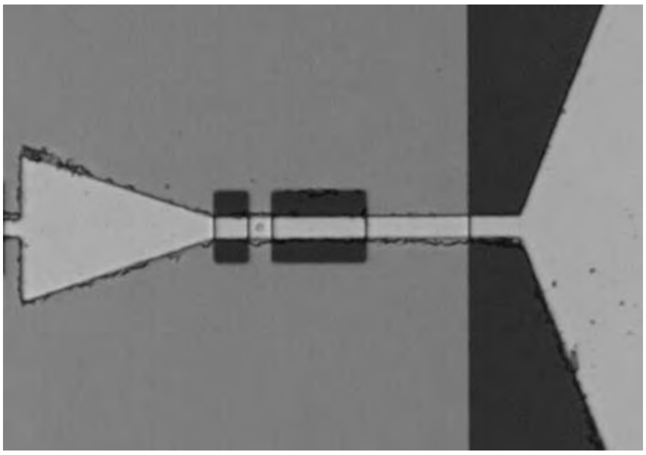

Fig. 6. Photo of the tuning circuit.

The junction capacitance is compensated by a parallel inductance consisting of a coplanar waveguide. In order to limit the parasitic capacitances and thus ensure a large IF bandwidth, the virtual ground has been realized using a delta-stub instead of the commonly used radial stub. Matching to the antenna impedance is achieved with a structure that can be viewed either as a CLCPW λ/4-transformer or as a discrete L-C transformer.

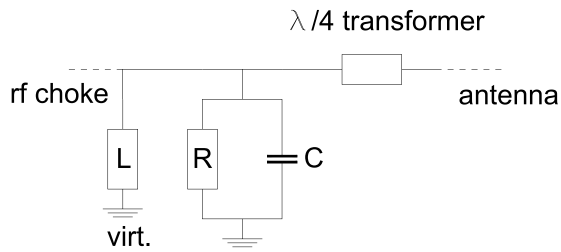

Fig. 7. Equivalent circuit of the tuning structure.

The achieved matching to the junction is quite homogenous over the whole frequency range as can be seen by the junction's embedding impedance plotted in the Smith chart in Fig. 8. The power coupled to the junction lies between 85 and 97% (see Fig. 9).

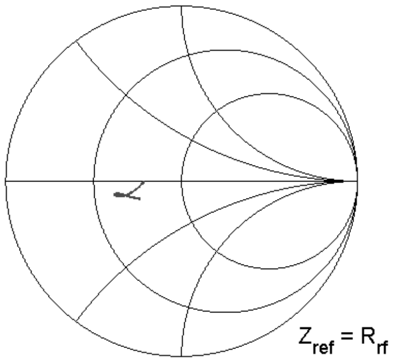

Fig. 8. Embedding impedance of the junction. Smith chart is normalized to the junction's RF impedance.

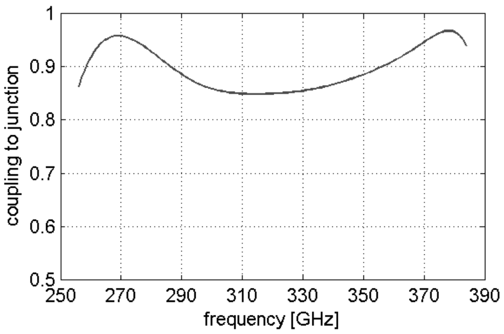

Fig. 9. Fraction of power coupled to the junction.

B. Mixer block and magnetic yoke assembly

The actual mixer block is a simple device. It only features a waveguide cavity and a substrate channel which allows to place the mixer chip just above the cavity (see Fig. 10, above). For DSB mixer testing the block is directly mounted onto a –16 dB LO coupler providing the input waveguide. In the 2SB mixer assembly the input waveguide is part of the waveguide coupler (see Fig. 2). The IF circuit consisting of a 50 Ω line realized as microstrip with a Rodgers 4003 substrate is mounted into a substrate holder which is fixed on top of the mixer block. The mixer chip is contacted via bonding wires to the block and the Rodgers microstrip (see Fig. 10, below). For the band 7 frequency range it is necessary to apply a local magnetic field to the junction in order to suppress Josephson currents which are a source of mixer noise and instability. Therefore a custom-made superconducting magnet and yoke assembly is attached to the mixer block (see Fig. 2).

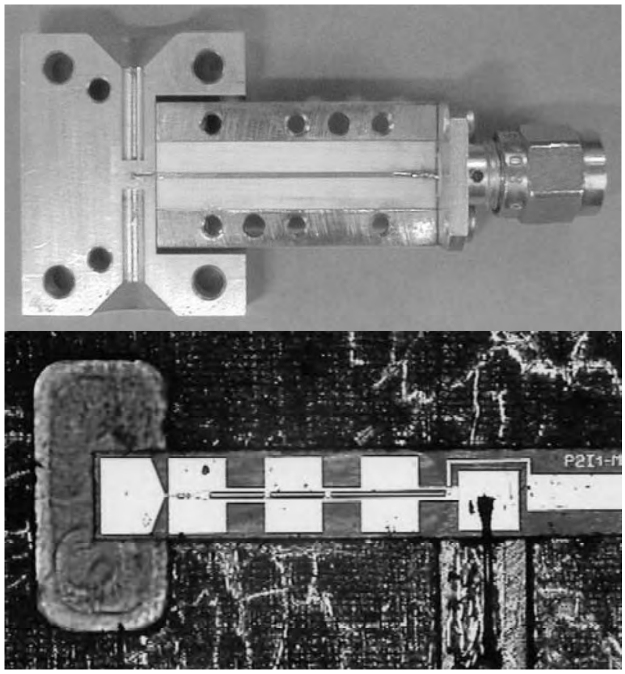

Fig. 10. Junction mounted into the mixer block. Above: Mixer block with holes for the magnetic yoke assembly and attached IF circuit. Below: Close-up of the mixer chip with the antenna mounted above the waveguide cavity.

C. Noise measurements

Several junctions from different wafers have been tested as DSB mixers. The best results so far were obtained with junctions from wafer 43. These junctions have a normal state resistance and area close to the design values. The best obtained DSB noise temperatures integrated over the 4 to 8 GHz IF band are presented in Fig. 11. The achieved values are better than 30 K over 85% of the RF band and increase up to 34 K for the highest frequency.

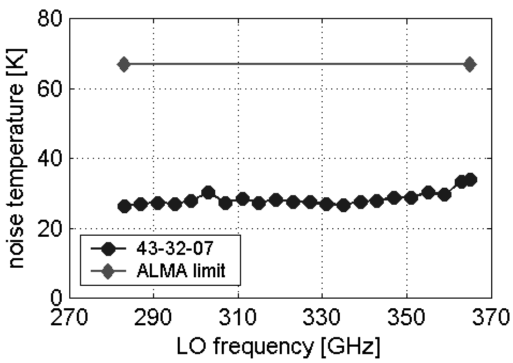

Fig. 11. Result of DSB noise measurements integrated over 4 to 8 GHz IF band.

IV. 2SB RESULTS

Two junctions from wafer 43 have been mounted together and tested as sideband separating mixer. The obtained noise temperatures for the two IF bands integrated respectively over the whole 4 GHz bandwidth are shown in Fig. 12. For the lowest frequencies the achieved noise temperatures are below 60 K rising with increasing frequency up to 95 K for the highest frequency. These results are well below the ALMA specification represented by the red line.

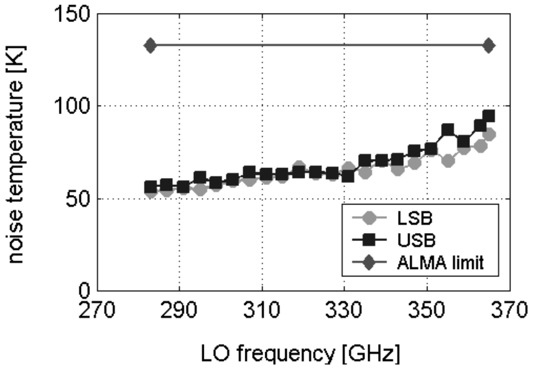

Fig. 12. Noise temperatures of sideband separating mixer with junctions 43-12-01 and 43-12-02. Measurements have been integrated respectively over each IF band of 4 to 8 GHz. The red line represents the ALMA limit.

ALMA mixers are submitted to a complete set of testing before they can be integrated into the cartridge. Apart from measuring the noise temperature integrated over the IF band for different LO frequencies (as shown in Fig. 12) IF sweeps with steps of 100 MHz are carried out for each of these LO frequencies and noise temperature and image rejection are measured.

Fig. 13 shows the results of such measurements for the image rejection over the RF frequency band. In general, values around –13 dB are achieved. Only a few points measured at the IF band edges are slightly above –10 dB.

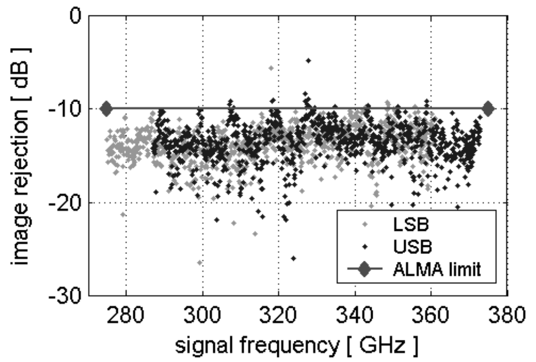

Fig. 13. Image rejection over the whole RF band resulting from the IF sweeps. Measurements obtained in the lower sideband are plotted in grey, those achieved in the upper sideband are represented by the black dots. The red line indicates the ALMA limit.

Fig. 14 shows the noise temperatures resulting from the IF sweeps as a function of the signal frequency. These are true SSB noise temperatures, corrected for the residual response in the image band. The achieved results are well below the ALMA specification indicated by the red line.

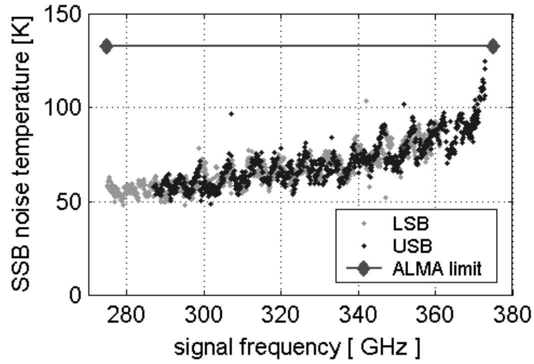

Fig. 14. SSB noise temperatures resulting from the IF sweeps. Measurements obtained in the lower sideband are plotted in grey, those achieved in the upper sideband are represented by the black dots. The red line indicates the ALMA limit.

V. Conclusions

A sideband separating mixer fulfilling the ALMA specifications for band 7 has been successfully developed, fabricated and characterized. Currently IRAM is working on the fabrication of 16 2SB mixer units for the production of a pre-series of 8 cartridges. The first cartridge has been equipped with two 2SB mixers and will be delivered this year.

References

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[4] CST Microwave Studio, Bad Nauheimer Str. 19, D-64289 Darmstadt, Germany

[5] Sonnet Software, 100 Elwood Davis Road, North Syracuse, NY 13212

[6] Advanced Design System, Agilent EEsof EDA