230 GHz SSB SIS mixer for band 3 of the new generation receivers for the Plateau de Bure interferometer

D. Maier, S. Devoluy, M. Schicke, and K. F. Schuster

***Abstract*—A single sideband SIS mixer with a 4-8 GHz IF band and covering the RF frequency range of 200 to 265 GHz has been developed and characterized. This mixer will be integrated into band 3 of the new generation receivers for the Plateau de Bure interferometer. LSB noise temperatures as low as 40 K could be obtained over the whole LO frequency range. USB noise temperatures are slightly higher.**

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

I. Introduction

IRAM is currently developing new generation receivers for the six element Plateau de Bure interferometer. These receivers will cover the four frequency bands 83-115 GHz, 129-174 GHz, 200-265 GHz, and 275-373 GHz, each with two polarizations, single-sideband operation, and an IF band of 4 to 8 GHz. Installation is foreseen before winter 2006/2007.

This paper presents design and characterization of a single sideband SIS mixer for band 3 (initially defined from 200 to 260 GHz) using a moveable backshort for image rejection.

II. RF design

The design of this mixer is quite similar to the one designed for ALMA band 7[1]. A layout of the mixer chip is shown in Fig. 1. The mixing element is a 1μm^2 Nb-Al/AlO$_x$-Nb tunnel junction made by e-beam lithography [2]. This junction is embedded into a superconducting circuit consisting of the antenna, the RF choke, and the tuning structure.

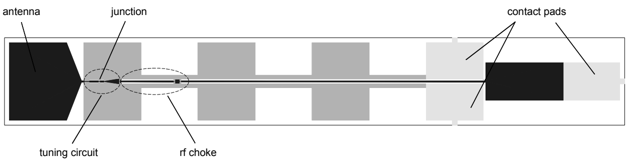

Fig. 1. Layout of the mixer chip with a size of 2.5 × 0.35 × 0.1 mm³.

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The antenna providing the full-height waveguide to suspended microstrip transition consists of a probe structure on a quartz substrate which is placed in a channel perpendicular to the waveguide axis and stretches partly into the waveguide as can be seen in Fig. 2. Behind the mixer chip a backshort can be moved inside the waveguide.

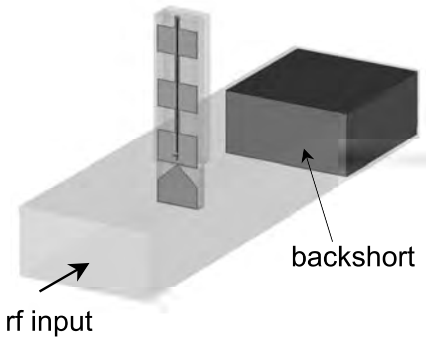

Fig. 2. Full-height waveguide to microstrip transition.

In order to evaluate the antenna impedance, simulations using CST Microwave Studio [3] were carried out for a large distance between junction and backshort. Fig. 3 shows the result of such a simulation for frequencies between 200 and 260 GHz and a distance of 30 mm between junction and backshort. The Smith chart is normalized to 60 Ω. Since the circles move around the center of the chart, antenna impedances around 60 Ω are obtained for matched backshort positions.

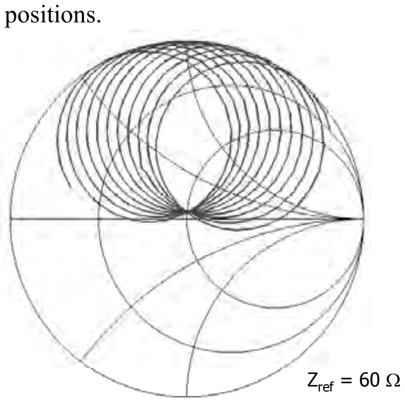

Fig. 3. Antenna impedances for frequencies between 200 and 260 GHz and a backshort distance of 30 mm. Smith chart is normalized to 60 Ω.

The superconducting tuning circuit is the same as in [1] adapted to the PdBNG band 3 frequency range using Sonnet [4] and ADS [5]. A photo of a fabricated mixer chip with a close-up of the tuning structure is shown in Fig. 4. The equivalent circuit is presented in Fig. 5.

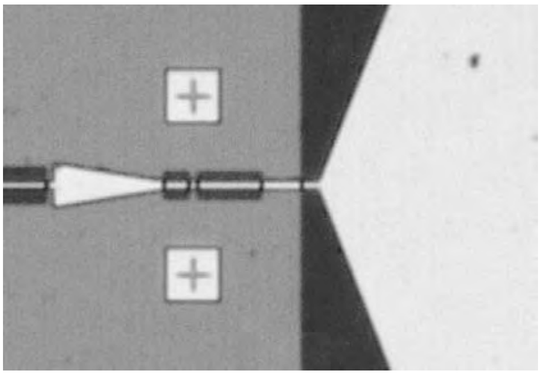

Fig. 4. Photo of the tuning circuit.

Compensation of the junction's capacitance is achieved with a parallel inductance consisting of a coplanar waveguide. A delta-stub creates the virtual ground. The delta-stub has been chosen in order to limit the parasitic capacitances and ensure a large IF bandwidth. A λ/4-transformer finally provides matching to the antenna impedance.

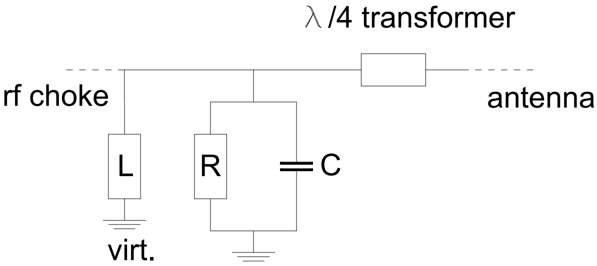

Fig. 5. Equivalent circuit of the tuning structure.

The mixer has been designed to work in USB mode for the upper end of the RF band and in LSB mode for the lower frequencies. In the middle of the band there is a choice of USB or LSB operation. For each LO frequency a backshort position can be found providing an optimum match at the USB (LSB) frequency and simultaneously presenting a reactive termination to the junction at the LSB (USB) frequency. Fig. 6 shows an example for a signal frequency of 230 GHz. The Smith chart on the left-hand side shows the embedding impedance of the junction for a backshort distance of 3.590 mm. For this backshort position the frequency band of 228 to 232 GHz is well matched whereas for frequencies between 216 and 220 GHz a reactive termination is presented to the junction. Hence, this position corresponds to observing at 230 GHz in USB mode. The Smith chart on the right-hand side in Fig. 6 shows the embedding impedance of the junction for a backshort distance of 6.085 mm. The frequency band of 228 to 232 GHz is still well matched, but now the junction sees a reactive termination for frequencies between 240 and 244 GHz. Accordingly the mixer is set to LSB operation for a signal frequency of 230 GHz.

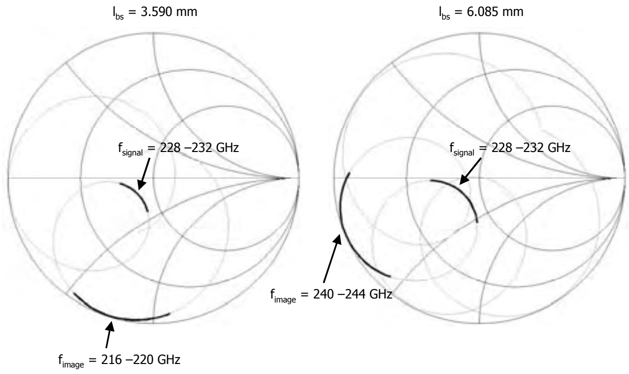

Fig. 6. Example of observing at 230 GHz. Left: Embedding impedance of the junction for a backshort distance of 3.590 mm corresponding to LSB operation at 236 GHz LO frequency. Right: Embedding impedance of the junction for a backshort distance of 6.085 mm corresponding to USB operation at 224 GHz LO frequency. Both Smith charts are normalized to the junction's RF impedance.

In order to obtain the matching of the junction over the whole RF frequency range backshort positions are determined for each LO frequency for both USB and LSB operation of the mixer and the junction's embedding impedance is calculated. The result is shown in the Smith chart in Fig. 7 for signal frequencies between 200 and 260 GHz for LSB (grey line) and USB (black line) operation.

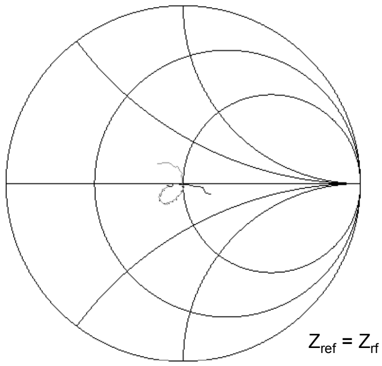

Fig. 7. Embedding impedance of the junction. Smith chart is normalized to the junction's RF impedance. LSB operation is represented by the grey line, USB operation is plotted in black.

A good match could be obtained over the whole frequency range as can also be seen by the plot in Fig. 8 representing the fraction of power coupled to the junction. For all signal frequencies more than 97% of the incident power is coupled to the junction. In the middle of the band USB and LSB operation give the same theoretical results. Hence, coupling to the junction does not depend on LSB or USB operation, but only on the signal frequency.

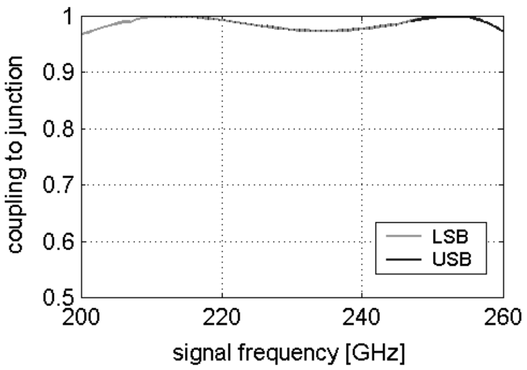

Fig. 8. Fraction of power coupled to the junction. LSB operation is represented by the grey line. The black line indicates results for USB operation.

III. Mixer block and magnetic yoke assembly

The actual mixer block consists of a front and a rear block with a waveguide going through both (see Fig. 9). A mechanism for moving the backshort inside the waveguide is fixed to the rear part. 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. A local magnetic field is applied to the junction in order to suppress Josephson currents, which are a source of mixer noise and instability. For this purpose a custom-made superconducting magnet and yoke assembly is attached to the mixer block (not shown on the photo). For mixer tests the block is mounted directly onto an LO coupler. In order to better demonstrate the RF input a feedhorn has been mounted onto the mixer block for the photo shown in Fig. 9.

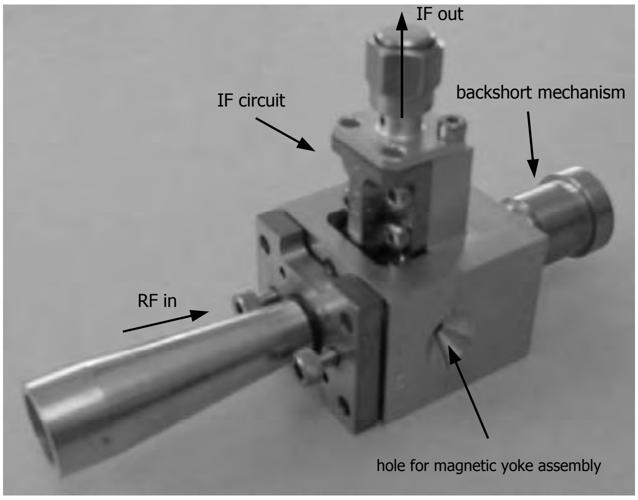

Fig. 9. Photo of the mixer block with feedhorn, backshort mechanism, and IF circuit.

IV. Noise measurements

So far only one batch of junctions with results for normal state resistance and area close to the design values has been fabricated and three junctions have been tested as mixers. A representative result of the noise measurements is shown in Fig. 10. For LSB operation noise temperatures around 40 K could be obtained over the whole LO frequency range (grey circles). USB noise temperatures are between 40 and 70 K (black squares).

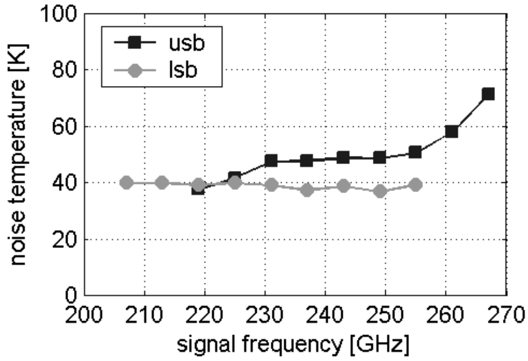

Fig. 10. SSB noise measurements of junction 11-34-02. LSB noise temperatures are represented by the grey circles. USB results are plotted with black squares.

The increase of noise for USB operation and signal frequencies above 255 GHz indicates that the junction's capacitance is higher than assumed in the design. Consequently the noise performance at the upper frequency end might be improved by employing smaller junctions.

V. Image rejection

Since the backshort position can only be optimized for the rejection of one distinct frequency, image rejection is a critical issue of backshort mixers, especially for large IF bands. Fig. 11 shows the image rejection obtained for an LO frequency of 231 GHz with the backshort set to USB operation. Note that the backshort position was not changed during the measurement. As expected, best values are obtained in the middle of the IF band. But even at the IF band edges an image rejection of better than –10 dB could be achieved.

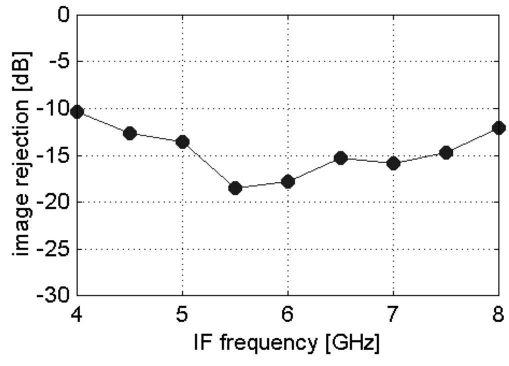

Fig. 11. Image rejection as function of the IF frequency measured for USB operation at f_{LO} = 231 GHz.

VI. Conclusions

A single sideband SIS mixer for band 3 of the new generation receivers for the Plateau de Bure interferometer has been successfully developed, fabricated and characterized. Initially designed for the RF frequency range of 200 to 260 GHz it works well up to 267 GHz, thus covering the later extended PdBNG band 3 frequency range of 200 to 265 GHz. Because of its low static capacitance it works without IF impedance transformer over the whole IF band of 4 to 8 GHz. Noise temperatures of 40 K could be obtained for LSB operation over the whole LO frequency range. USB noise temperatures are between 40 and 70 K and might be improved by employing smaller junctions.

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[5] Advanced Design System, Agilent Eesof EDA