First Results of the Sideband Separating Mixer for 850 GHz

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Abstract— **We presented here the design and the first results of a new sideband separating (2SB) mixer for 800--950\,GHz, based on superconductor-insulator-superconductor (SIS) junctions. This is the first waveguide 2SB SIS mixer demonstrated at such a high frequency. The design is following the classical quadrature hybrid architecture, meanwhile additional attention was put on the reduction of reflections in the RF structure in order to minimize the RF imbalance, to achieve a high image rejection ratio (IRR). The RF waveguide block was manufactured by micro-milling and populated by single-ended SIS mixers developed earlier for upgrade of the CHAMP+ high band array on the APEX telescope. These SIS mixers have DSB noise temperatures from 210 to 400\,K. The assembled 2SB mixer yields a single-sideband noise temperature from 450 to 900\,K, with an image rejection ratio above 15dB in 95\% of the band. Comparing the DSB and SSB sensitivities, we find that the waveguide losses are as low as expected and do not exceed 0.6\,dB. The presented mixer is a prototype for use in a 2SB dual polarization receiver planned for deployment on the APEX telescope.**

Index Terms— **Sideband separating (2SB) mixers, image rejection ratio (IRR), submillimeter wave technology, terahertz receivers, superconductor-insulator-superconductor junctions.**

I. INTRODUCTION

Ground based observations of astronomical objects at frequencies around 800--950\,GHz are strongly influenced by atmospheric absorption. Using sideband-separating (2SB) receivers instead of double-sideband (DSB) ones allows us to reduce the atmospheric noise contribution for spectral line sources by, ideally, a factor of two, irrespective of the actual atmospheric transparency. In practice, however, the total system noise temperature includes other contributions like mixer noise and intermediate frequency amplifier noise. These make a factor of two improvement in system noise temperature unobtainable. In addition, the actual improvement will strongly dependent on the atmospheric transparency. From historical weather conditions at the [1] and ALMA [2] sites [3], the zenith atmospheric transmission for the 800—950 GHz window can be estimated between 0.2 and 0.6. The upper limit corresponds to realistic good weather conditions, while the bottom one represents the limit at which the atmospheric opacity becomes too high for reasonable observations in this band. Within this range, the ratio of the 2SB and DSB sensitivities for spectral line observations will be on average around 1.3 for an effective atmospheric temperature of 260 K, and a state-of-the-art single sideband (SSB) mixer noise temperature of 300 K [4]. This number gives sufficient motivation to develop sideband separating receivers for this frequency range.

II. MIXER DESIGN

For the 2SB mixer we chose a modular design concept very similar to one for the 600—720 GHz band [5][6]. In this concept, the critical components like RF hybrid block, RF horn, LO horn and SIS holders (“back pieces”) are realized as independent units, which can be easily exchanged and tested individually. This allows convenient DSB characterization of the individual SIS devices for matching purposes. Both LO and RF horns have a diagonal spline design

The quadrature hybrid is a typical five-branch coupler similar to presented in [7]. The main design goals were the reduction of the input reflection S_{11} and the isolation S_{21}. This was done by varying the relevant dimensions (mainly slot widths and positions) while keeping the phase and amplitude balance within reasonable limits (about 0.5 deg and 0.5 dB, respectively).

III. TEST RESULTS

The tested RF block and two horns were machined in-house at the Max Plank Institute for Radio Astronomy (MPIfR) in Bonn out of CuTeP (ASTM C14500) alloy. A liquid He cryostat was used to cool down the mixer. The noise temperature was determined with a 300/77 K hot-cold Y-

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factor measurement. At the same time, the image rejection ratio was characterized according to the method described in [8] by injecting a test tone signal through a 6\,\um\ Mylar beam-splitter (6 % coupling). Both noise signal and the test tone were coupled to the mixer through a quartz window and cold reflective optics. The LO signal is applied through a separate window in the cryostat. Two LO multiplier chains were used, together covering the entire 800-950 GHz band.

The measured uncorrected single-sideband (SSB) noise temperature of the prototype mixer is shown in Fig. [1]. It varies from about 550 to 1000 K over the band. The presented USB and LSB curves can be corrected for the fraction of the 300 K noise coupled through the beam-splitter and the LO waveguide coupler (4 %; -13 dB in waveguide LO coupler minus 1 dB of additional loss in the LO path). The noise temperature corrected for these two factors will be in the range 450 to 900 K. To have an estimate of the noise penalty incurred by the waveguide structures, the sum of the DSB noise temperatures of the individual SIS mixers is presented on the same plot. It should be mentioned, that the DSB data was obtained using the same cryostat window, cold optics, IF amplifiers and isolators. For clarity, the DSB data points represent the noise temperature averaged over the 4-12 GHz IF band. From the plot, one can estimate that the corrected SSB noise temperature will be higher than the doubled DSB one by 0 to 30 % and on average about 15 %. This is in a good agreement with the waveguide losses theoretically estimated at 0.6 dB or 15 %.

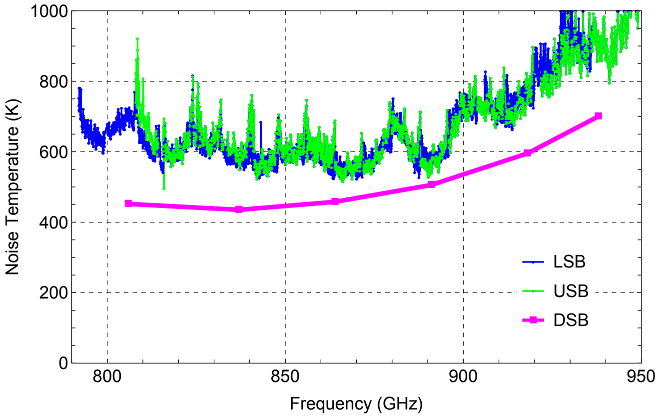

Fig. 1 Uncorrected single-sideband noise temperature of upper (USB) and lower (LSB) sidebands as function of the RF input frequency. The plot is stitched from individual 4-12 GHz IF measurements, while the LO step was 8 GHz, giving full coverage. The frequency resolution within each set is 40 MHz. For reference, the sum of the DSB noise temperatures of the two individual SIS mixer devices is plotted as well (average of two measurements). The DSB data is an averaging product over the 4-12 GHz IF band, and the points are plotted versus the LO frequency in this case.

Fig. [2] shows the image rejection ratio (IRR) obtained with the first prototype block. The IRR is above 15 dB in almost all the points, only at the end of the band it goes down to about 13 dB overall. A few points are falling down to 10 dB level, for example around 860 GHz, which is an artifact of the measurements. It is caused by phase noise and spurious harmonics in the LO signal. Nevertheless, the current results are very promising and a receiver based on this mixer has clear potential to fit ALMA-class specification of 10 dB with ample margin.

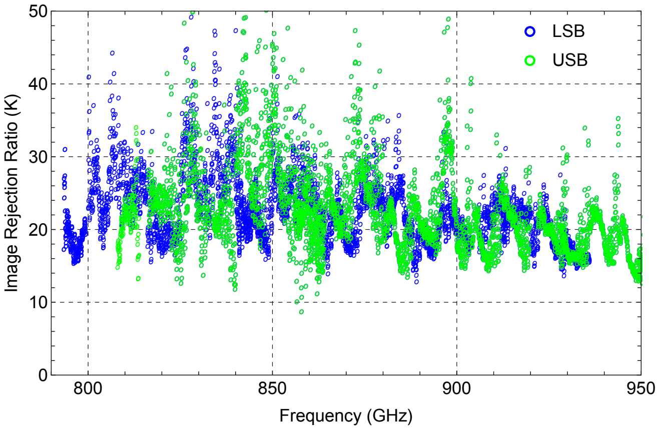

Fig. 2 Image rejection ratio with the same 2SB mixer block and SIS devices. Both LSB and USB results are presented. The data points are measured with step of 40 MHz.

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