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Multipixel FPA demonstrator composed of 2SB SIS mixer receivers operating around 1 THz

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COVID-19 affects the Deliverable D5.6, to which the Art.51 applies as follows:

2SB SIS mixers operating near 1 THz (800-950 GHz) have been developed and several mixers have been successfully tested in the lab. These mixers will be installed at APEX telescope as a part of nFLASH receiver. Due to COVID-19 travel restriction the installation campaign has been delayed for more than a year. Tests at APEX are planned ⇒ the original plan of constructing an FPA cannot be achieved in time.

1 Executive Summary

The main goal of this part of development is to develop and demonstrate a focal plane array (FPA) building blocks in frequency range of 500-1000 GHz which are based on a SIS mixer technology. SIS mixer technology in this frequency range has the lowest noise temperature and widest IF frequency range available in comparison with other techniques. At lower frequencies a more complex sideband separation SIS mixers has been demonstrated already for instance in lower frequency ALMA [1] bands 5-7 [2], [3]. For 500-1000 GHz such a complex mixers is a technological challenge as they demand very small waveguide sizes and tight amplitude and phase balance between the components. We have designed and built two prototype 2SB SIS mixer blocks operating in the frequency range of 780-950 GHz which aligns with ALMA band 10 and the corresponding atmospheric transmission window. We have built laboratory measurements set-up and characterised sensitivity and sideband ratio of these mixers. SSB noise temperature below 500 K and excellent sideband ratio of better than 15 dB has been demonstrated which makes these mixers suitable for installation on the APEX telescope [4] taking advantage of its high antenna accuracy. This is planned for year 2021-2022 observing campaign. This work is first experimental realization of a waveguide 2SB mixers at this frequencies.

2 2SB SIS mixers in 780-900 GHz frequency range

2.1 2SB SIS mixer block and device technology

The 2SB mixer design layout is based on classical scheme utilizing a quadrature hybrid to split the input RF signal between two DSB mixers with 90 degree phase shift while local oscillator (LO) signal is coupled to the mixers in phase. The intermediate frequency (IF) outputs from the mixers are recombined using another quadrature hybrid working at 4-12 GHz frequency range. Two outputs of the IF hybrid, lower sideband and upper sideband are connected to IF cryogenic isolators followed by a cryogenic IF amplifiers. The IF amplifiers and IF hybrid has been developed by OAN YEBES group and delivered as part of RADIONET collaboration. The RF quadrature hybrid and LO coupling network is based on the waveguide technology. Both structures are machined into copper split-block using high accuracy CNC milling process. Typical smallest dimensions are of order of 70 microns with machining accuracy is of order of 2 microns. Building blocks of 2SB mixers are shown in fig 2-1-1 and fig 2-1-2.

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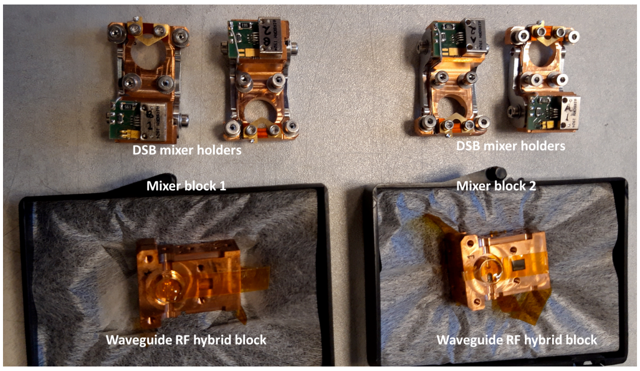

Fig. 2.1-1 Disassembled 2SB Mixer blocks containing waveguide quadrature hybrid and LO insertion couplers machined into a split-block (below) and DSB mixer holders that contain DC contacts, temperature sensors and de-flux heater contacts for elementary DSB mixers that will constitute 2SB mixer block.

The fully assembled 2SB mixer block is shown in figure 2-1-3. It also contains corrugated horns which form both LO and signal optical beam. This construction is similar to lower frequency 600-720 GHz 2SB mixer blocks developed also in the framework of radionet project [5], [6, p. 2], [7]

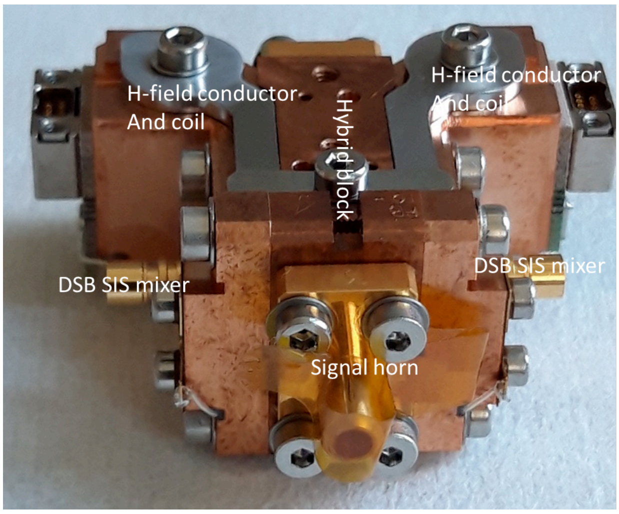

Fig. 2.1-2 Fully assembled 2SB mixer block containing LO and signal horns, two DSB mixers, hybrid block, magnetic field H-field coils and flux conductors and cryogenic/mechanical mounting interface.

2.1.1 DSB SIS mixers

DSB SIS mixers are key building blocks of a 2SB design and determine its noise performance. We have developed SIS mixers based on Nb-AlN-NbN tunnelling structure which allows for higher energy gap and extends the biasing operating range. A 0.5 micrometer square area SIS junction is embedded in a microstrip tuning network based on 300 nm thick NbTiN ground layer, 250 nm thick Silicon Dioxide insulator layer and 500..700 nm thick Aluminum wiring layer. This material combination allows for good performance for frequencies above gap frequency of Nb (690 GHz) because of higher critical temperatures of used superconductors or replacing superconductor by a normal metal in case of Aluminum wiring. The planar tuning/coupling structure of the SIS mixer and its waveguide environment as well as waveguide hybrids have been optimized using CST Microweve studio 3D EM package. For this purpose model of superconducting layers including kinetic inductance and frequency dependent losses has been introduced in the package. [8], [9]

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2.1.2 Laboratory performance evaluation and results

The assembled 2SB mixer blocks has been mounted into vacuum space of liquid helium cryostat which allows to achieve operating temperature of 4.2K as shown in figure 2.1.3. The cryostat also contains IF amplifiers, IF hybrid and a reflective input optics which transforms wide angle beam from mixer RF horn to naoorw angle beam at cryostat input window. The LO signal is also coupled in through dedicated window. Both LO and signal windows paths contain goretex infrared rejection filters.

The standard Y-factor technique has been used to measure the receiver noise temperature. Absorbers immersed into liquid nitrogen bath and at the room temperature were used as calibrators. To evaluate receiver sideband ratio we have inserted a small test tone signal at known frequency into receiver path using a 12 micron thick mylar foil beam splitter and focussing elements. Sideband ratio has been determined by comparing leakage of the test tone signal from LSB to USB channel. The frequency of test tone and LO then has been adjusted to measure sideband ration and receiver noise temperature across the entire RF and IF band of the mixer blocks.

Typical noise temperature of built 2SB block is shown in figure 2-1-4 both for USB and LSB channels. Full frequency coverage has been achieved and competitive SSB noise of 500 K has been demonstrated for most part of the band. The noise temperature increase towards higher part of the band can be explained by increased losses in SIS junction tuning structure due to impurities in superconducting layers. The noise peaks in the plot are artefacts of measurements system and are due to noise from LO CW source and harmonics generator. This noise is produced by external components and will be mitigated at telescope by choice of low noise components.

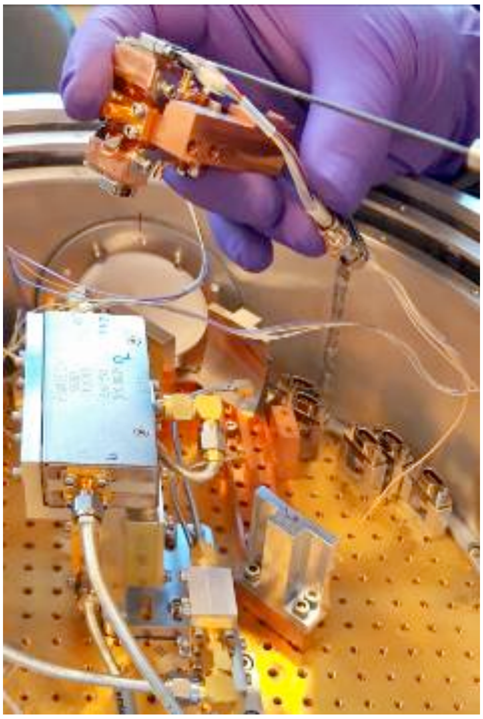

Fig. 2.1-3 2SB mixer block is mounted into vacuum space of the liquid helium cryostat.

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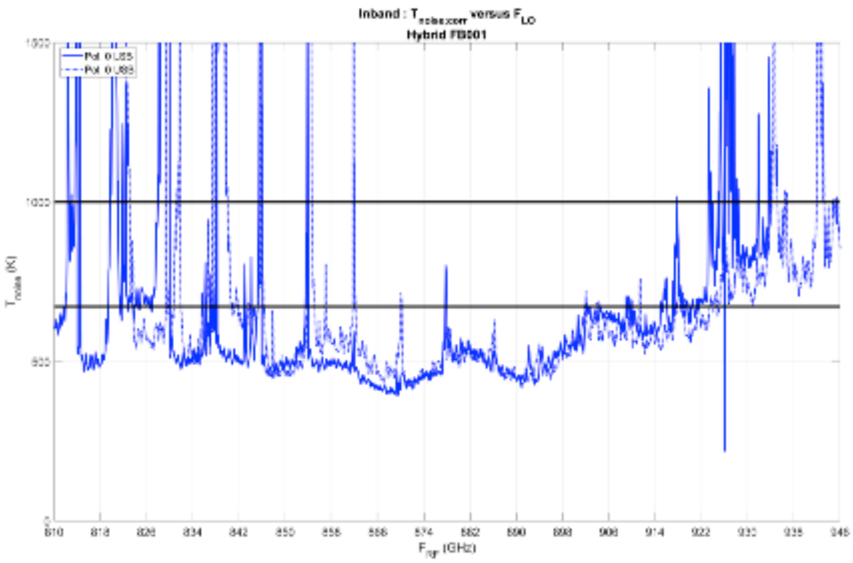

Fig. 2.1-4 Measured SSB noise temperature of hybrid block 1, corrected for input optics contribution. Both lower sideband channel (LSB) and upper sideband channel are present and show similar performance. The noise temperature is plotted vs. a RF frequency. Noise peaks are caused by harmonics in our set-up test tone source as well as noise coming from our lab LO source which will not be present at the real operation at the telescope.

The measured sideband ratio is presented in figure 2-1-5. It shows average number of 15 dB which is sufficient to suppress most of the atmospheric noise from the image sideband. This value also demonstrates that an excellent amplitude and phase balance has been achieved both in RF and IF quadrature hybrids.

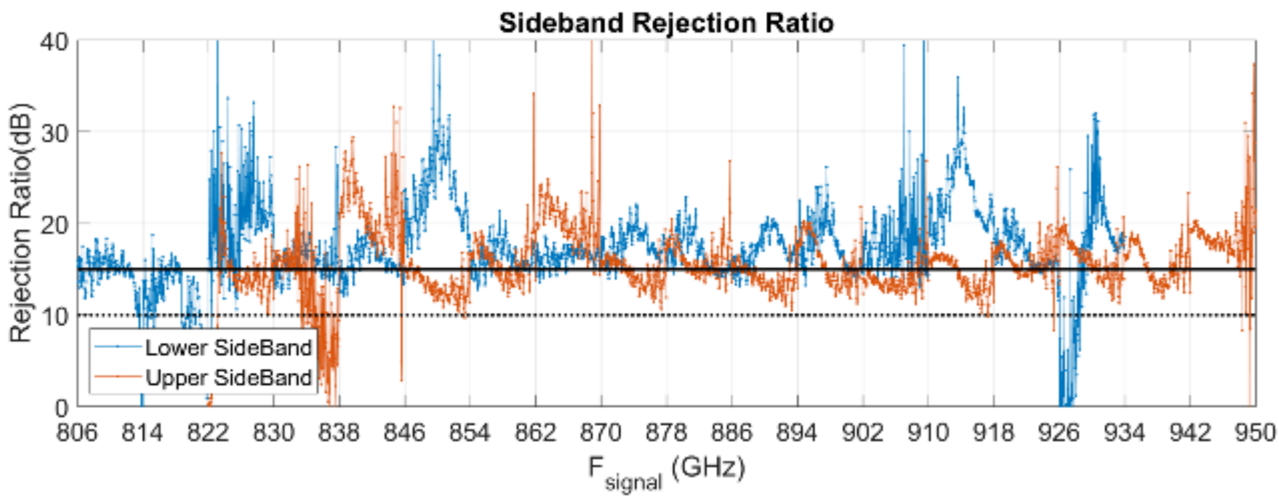

Fig. 2.1-5 Measured 2SB block sideband rejection ratio v.s signal frequency. Results are presented both for USB and LSB channels.

3 Conclusion

We have developed and manufactured two sideband separating mixers in the frequency range of 780-950 GHz, based on SIS junction technology. These mixers have been evaluated and demonstrate low noise and high sideband ratio, which makes them suitable for use in nFLASH receiver at APEX telescope. We plan to install these mixers into nFLASH receiver in the course of the year and evaluate their performance in the telescope environment using sky astronomical signals on top of the sky background. The same mixer will be used for astronomical observations in the THz frequency range.

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