Development of 1 THz SIS mixer for SOFIA

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Abstract

We report the development of a low noise and broadband SIS mixer aimed for 1 THz channel of the Caltech Airborne Submillimeter Interstellar Medium Investigations Receiver (CASIMIR), designed for the Stratospheric Observatory for Far Infrared Astronomy, (SOFIA). In the SIS mixer are used the Nb/AlN/NbTiN junctions with the Josephson critical current density of about 40 KA/cm^2. The mixer is built using a double-slot quasi-optical design and covers a 250 GHz band centered at 1 THz. The minimum measured receiver noise is about 353 K (Y=1.50). The receiver noise may be reduced using a higher level of LO power. The developed mixer will allow building a receiver with the noise temperature approaching 250 K in 1 THz band and having a broader operation band compared to the previously reported.

Introduction

The Earth atmosphere is nearly opaque at the Terahertz frequencies and one has to use the orbital or sub orbital platforms for astronomical observations in THz band. The Stratospheric Observatory for Far Infrared Astronomy (SOFIA) [1] is an example of such sub orbital platform. The observatory is based at a 747 Boeing flying a 2.5 meter telescope at an altitude up to 14 km. A high cost of SOFIA operation and a limited observation time is making the sensitivity of the detectors, and thought the speed of the detection, a vital priority in this project.

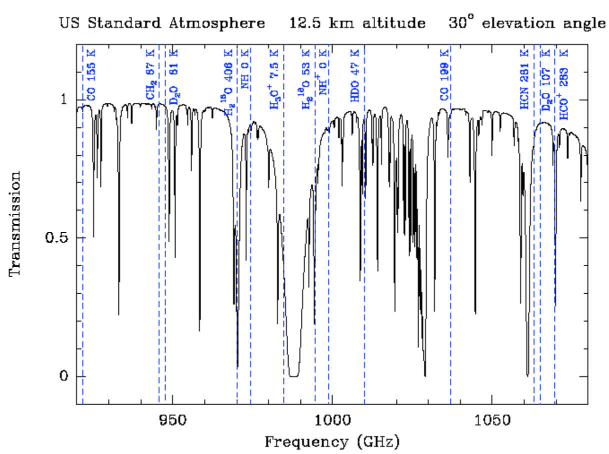


Fig.1 The atmospheric transmission in 0.9 – 1.1 THz band of SOFIA observatory flying at 12 km altitude with telescope at 30 degree elevation angle calculated using ATM [2]. A number of interesting molecular lines is located at the frequencies with nearly ideal (90-95%) transmission of the atmosphere. The atmospheric background noise is below the quantum limit of the heterodyne receivers.

An example of transmission of the atmosphere for SOFIA flying at 12 km altitude and for the telescope elevation angle of 30 degree is presented in fig. 1. The transmission has been calculated using ATM model [2]. Outside of relatively narrow absorption lines of the earth atmosphere the transmission may be as good as 95 - 90%, resulting in the atmospheric background noise temperature as low as 15-30 K. The quantum limit of the noise of a DSB heterodyne receiver is about $T_N = h\nu/2k \approx$ 24 K at 1 THz [3] and this noise level is comparable with the atmospheric background noise. Therefore the development of a receiver approaching the quantum limit of sensitivity in 1 THz band may substantially improve the capability of SOFIA.

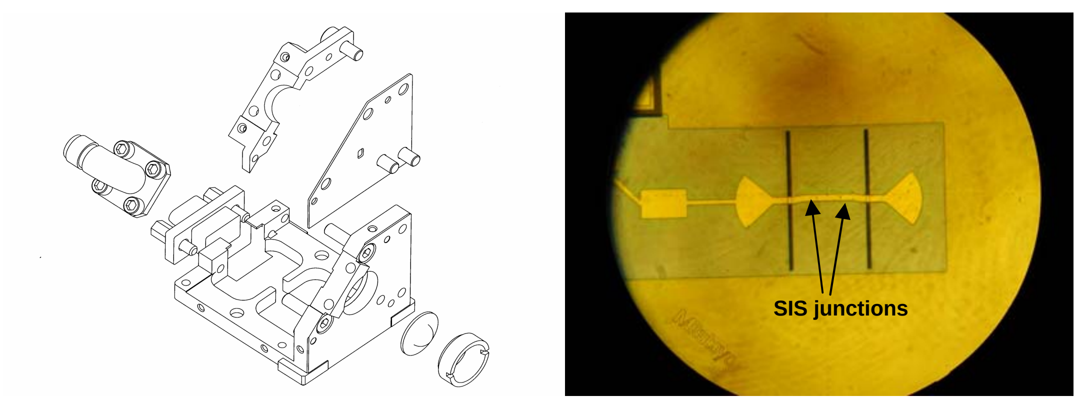
SIS mixer design

We developed a SIS mixer using a high critical current density Nb/AlN/NbTiN junctions with the normal state resistance to area product $R_N A$= 6 Ohm µm^2 [4]. The two SIS junction circuit is coupled to the double slot antenna. We are using epitaxial Nb ground plane and a gold wire layer to form the matching circuit of the SIS mixer.

Due to a low resistivity of the epitaxial Nb film of about 0.2 µOhm cm, the loss in the mixer circuit is relatively low. Another advantage of the design using epitaxial Nb ground plane instead of NbTiN is a much better tolerance to the manufacturing errors. The 1 THz frequency is well above the gap frequency of Nb F_{gNb}=700 GHz, and so at 1 THz Niobium behaves as a normal metal. Therefore at 1 THz a microstrip circuit made off Nb has no reduction of the speed of propagation of the signals related to the kinetic inductance. A manufacturing error in length or in positioning of the circuit parts is leading to an error in the phase length of the circuit elements. The error is smaller if Nb ground plane is used instead of NbTiN. This advantage may be particularly important for development of multybeam receivers, where a big number of identical mixer is required.

The mixer housing design is presented in the fig.2 a. It is similar to one used in our work on 1.2 THz SIS mixer [5]. The mixer housing consist of the base frame, of the IF and DC bias board, and of the IF and DC connectors. A Silicon lens with the mixer chip on it back side is fixed in a hole at the front plane of the mixer housing. The mixer chip layout is in the figure 2 b. It is a twin SIS junction circuit coupled to a double-slot planar antenna.

The model prediction of the mixer on-chip coupling is presented in fig. 3. For modeling we used the SUPERMIX [6] software package. The predicted mixer response is centered at 1 THz and should be about 250 GHz wide. The measured FTS response matches well the model prediction (fig. 3).



a) b)

Figure 2 a) The mixer housing of a 1 THz SIS mixer developed for SOFIA. It is similar to one used in our work on 1.2 THz SIS mixer [5]. The mixer housing consist of the base frame, IF and DC bias board, IF and DC connectors. A Silicon lens with the mixer chip on it back side is fixed in a hole at the front plane of the mixer housing. b) The 1 THz mixer chip layout. The mixer has a twin SIS junction circuit coupled to a double-slot antenna.

Experiment

The test receiver used in our experiment consists of an Infrared Laboratories LH-3 cryostat, of the local oscillator, and of the bias electronics. The cryostat vacuum window is in Mylar 12 µm thick. An infrared filter made of Zitex is located at the 77 K stage of the cryostat. The local oscillator power is coupled to the mixer beam using a Mylar beam splitter 13 micron thick. The intermediate frequency range is 4 GHz –

8 GHz and the IF amplifier noise is about 3 K. During the test the physical temperature at the mixer block was about 2 K.

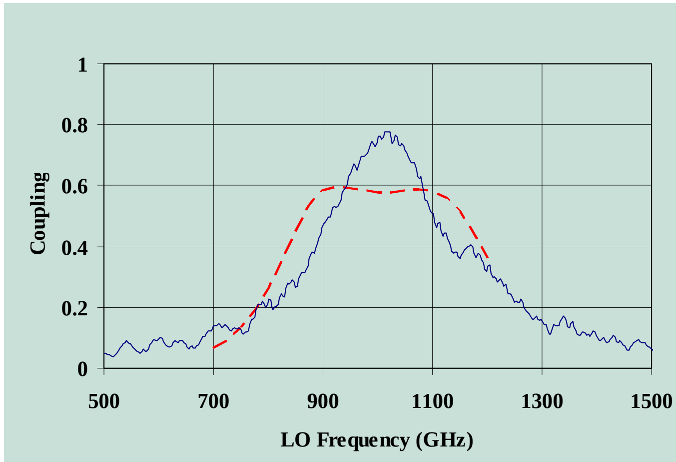


Figure 3. The model prediction of the 1 THz mixer on-chip coupling (dashed line) and the measured FTS response (continues line). The measured FTS response matches well the model prediction.

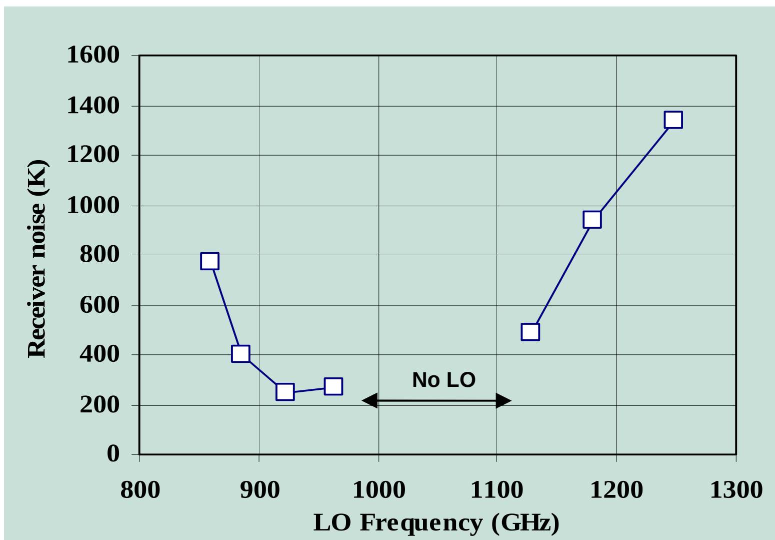


Figure 4. The measured receiver noise corrected for the loss in the LO injection beam splitter. The receiver band is about 250 GHz and it is centered at 1 THz. The break in the curve corresponds to the band with no LO available. The minimum receiver noise corrected for the loss in LO coupler is about 250 K.

We used the Y-factor method for the measurement of the receiver double sideband noise. The ambient temperature and the liquid-nitrogen cooled loads are used as the reference signal sources. The minimum measured receiver noise temperature is T_{REC}=353 K (Y=1.50) at 924 GHz. The receiver noise corrected for the loss in the 13 µm thick Mylar beam splitter is presented in the fig. 4. In a good agreement with the mixer design requirements the measured receiver bandwidth is about 250 GHz and is centered at 1 THz frequency. The minimum receiver corrected noise temperature is 250 K. We had no LO coverage for some part of the receiver band.

The level of available LO power was limiting the receiver sensitivity. An example of the receiver performance as a function of LO power level is presented in the fig. 5. The receiver noise and the mixer conversion gain are plotted as a function of the Local Oscillator induced DC current, The SIS junction bias voltage was fixed at V=2.12 mV and the LO frequency was 964 GHz. The receiver noise is corrected for the loss in the 13 µm thick LO beamsplitter. It is visible that the conversion gain and the mixer noise may be improved at a higher level of LO power (fig. 5).

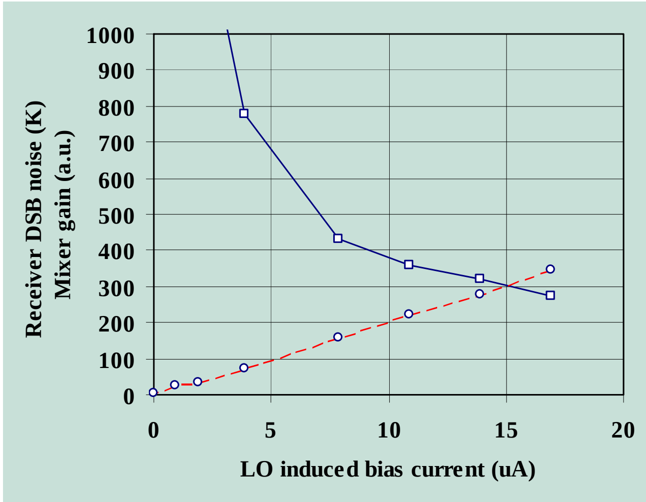


Figure 5. The receiver noise and the mixer conversion gain are plotted as a function of the Local Oscillator induced DC current. The SIS junction bias voltage is fixed at V=2.12 mV and the LO frequency is 964 GHz. The receiver noise is corrected for the loss in the LO beam splitter. It is visible that the conversion gain and the mixer noise may be improved at a higher level of LO power.

Conclusion

We developed a broad-band low noise SIS mixer for 1 THz channel of CASIMIR instrument of Stratospheric Observatory for Far Infrared Astronomy (SOFIA). The mixer band of operation is 0.875 – 1.125 THz, about 250 GHz wide. The minimum DSB receiver noise measured in our test receiver is 353 K (Y=1.50). The receiver noise corrected for the loss in the LO injection beam splitter is 250 K. The Local Oscillator power level in our test was below an optimal level, and the mixer performance may be improved using more LO power. The developed mixer appears to be a prospective element for construction of a low-noise heterodyne receiver for SOFIA.

Acknowledgment

This work is supported by SOFIA USRA instrument development program.
The authors would like to thank Imran Mehdi (JPL) for the loan of 1 THz local oscillator.

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