The design of a 230GHz unilateral finline SIS mixer

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Abstract: We present the design and the testing results of a broadband Superconducting-Insulating-Superconducting (SIS) unilateral finline mixer operating across 185*GHz*~275*GHz*. The mixer will be employed by a single baseline interferometer [1](Gubbins -200*GHz* Ultra-BroadBand Interferometer for Sunyaev-Zel’dovich), aiming to detect the Sunyaev-Zel'dovich effect [2][3] in bright galaxy clusters. A key feature of the design is the ultra-wide instantaneous bandwidth of 3-13 *GHz*. It provides heterodyne interferometeric operation with high brightness sensitivity, which enables the instrument to observe the continuous source precisely. The mixer chip has been carefully designed to present low parasitic reactance, in order to realize the wide IF bandwidth. A unilateral finline [4] has been used as the efficient transition between the waveguide mode and the slotline quasi-TEM mode over wide RF bandwidth. A direct coupling slotline-to-microstrip transformer is then used to couple the RF signal from the narrow slotline to the microstrip line, where the Nb-AlO$_x$-Nb SIS junction is fabricated. A silicon substrate was chosen to decrease the impedance of the slotline. The material of silicon enables easier extraction of devices from the substrate, by creating trenches around the individual devices using RIE etching. The hot/cold measurement of the mixer gave a DSB noise temperature of 90*K* over the bandwidth 200*K*-250*K*. In this paper we shall describe the design of the mixer and report the experimental results.

Keywords: Heterodyne Detector, Unilateral finline, SIS junction

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1. INTRODUCTION

In recent year, considerable effort has been invested in the development of SIS mixers for millimeter and sub-millimeter band receivers. In most cases however this was done for high resolution spectroscopy telescopes such as JCMT, ALMA, etc. The mixer described in this paper however was developed for a low resolution CMB interferometer. By having a very wide instantaneous bandwidth the mixer can have sensitivities comparable to those obtained by state of the art bolometers and yet maintain the advantages of heterodyne detection. Gubbins is expected to measure the Sunyaev-Zel'dovich null frequency in the Cosmic Microwave Background around 217*GHz* with high brightness sensitivity, which is achieved by the wide IF bandwidth SIS mixers

Another key feature of the mixer is the employment of a unilateral finline transition from the waveguide to a slotline on a silicon substrate. It prevents IF signals from propagating to the RF port and does not employ any complex transformers. This is because the cutoff frequencies of the slotline are well above the highest IF frequency. In addition, the unilateral finline transition is deposited in single layer, both simplifying the fabrication and avoiding shorts between the fins. Also, the employment of a silicon substrate allows the generation of trenches around individual chip during fabrication, simplifying the process of separating chips from the wafer. The relatively high dielectric constant of the silicon improves the matching between the slotline and microstrip, and also decreases the substrate thickness.

The mixer chip employed in this work was fabricated at KOSMA, University Cologne. The device is a Nb-AlO$_x$-Nb SIS tunnel junction of $1\mu m^2$ area fabricated in a 20Ω microstrip. This exhibits a capacitance of 75 fF that needs to be tuned out using planar circuits over the RF bandwidth.

2. The SIS MIXER CHIP

The configuration of the SIS mixer chip described above is illustrated in Fig.1 (Lower). A two-stage notch transformer was formed in front of the $60\mu m$ silicon substrate to match the loaded waveguide to the free space. A unilateral finline, deposited on the substrate, is used here to enable a broadband waveguide to microstrip transition to couple power to the SIS mixer. The configuration of the taper was calculated carefully using both the spectral-domain analysis (SDA) and the transverse resonance method. Quarter wavelength serrations are added to each side of the finline to prevent RF power propagating in the waveguide grooves of the mixer block. The wide RF bandwidth transition from the slotline to the microstrip was achieved by crossing the slotline with the microstrip and terminating each with a ~ $\lambda/4$ radial stub. In this way the signal propagating in the slotline sees an open circuit hence is guided to propagate in the microstrip that is terminated by a short circuit. An inductive microstrip stub and a three stage-chebyshev transformer tune out the junction capacitance. This combination matches the capacitive impedance of the junction to the resistive impedance of the transmission line over a wide bandwidth. A three stage RF choke is designed after the SIS junction to prevent the RF signal from propagating to the IF port. The tuning circuit is shown in Fig. 1(upper). All the circuits designed referred above were simulated in HFSS to verify the results.

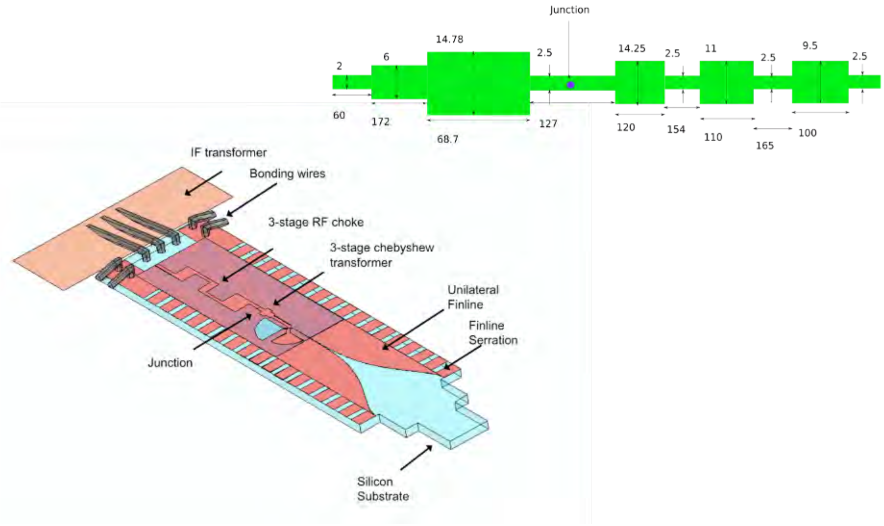
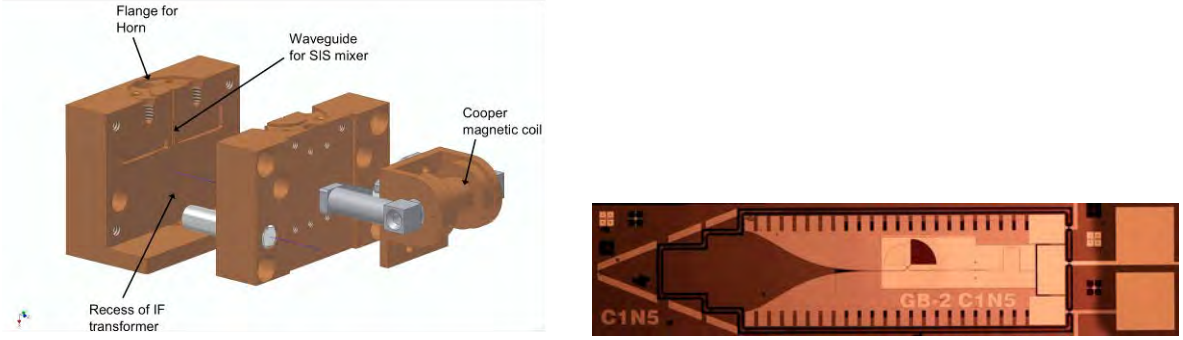


Fig.1 (Upper) Tuning ciruit--dimensions are in microns. (Lower) Mixer chip

3. MIXER BLOCK AND THE IF ARRANGEMENT

A high precision cooper split-block was fabricated in the University of Arizona (see Fig. 2(a)). The SIS mixer sits in the groove wall, which is the E-plane of the WR-4 waveguide. After the waveguide, there is a recession in the block, accommodating the IF transformer board. Two or three aluminium bond wires are used to connect the IF transformer board with the SIS mixer bonding pad. Suppression of Josephson pair tunnelling was achieved by a ~2000 turns superconducting coil wound on an iron former as shown in Fig. 2 (a). Several Josephson nulls can be swept by changing coil current from 0-100 *mA*. RF power and LO signal is fed to the mixer block waveguide by a corrugated horn antenna, which bolted in the front of the block.



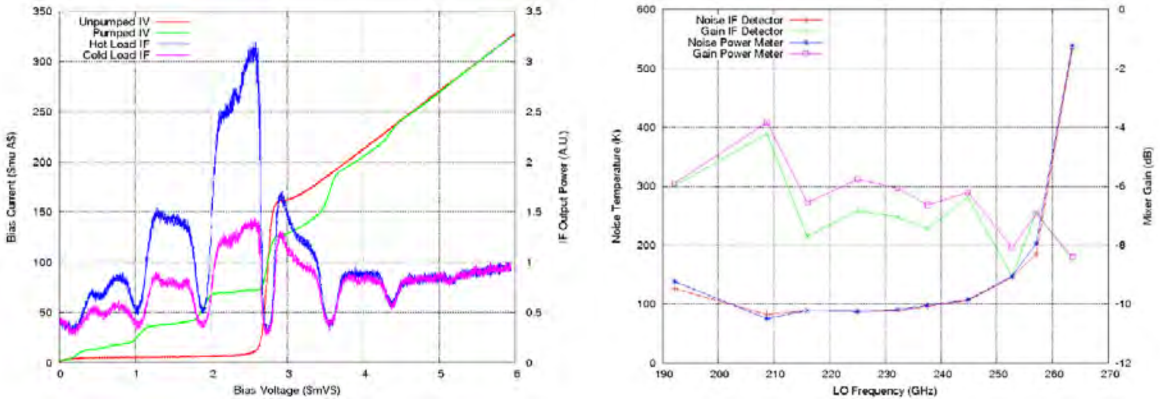
(a) (b)

Fig.2 The mixer block (a) and photo of mixer chip prior to dicing and mounting (b)

4. Experiment Results

The mixer sensitivity was tested in a liquid helium cryostat (~4 *K*) using the hot (300 *K*) and cold (77) load. RF signals were coupled to the mixer through a polythene window in the Dewar. An optical system on the bench guided the LO power using a 20μm beam splitter and the incoherent signal from the load into the SIS mixer. The IF signal at the output of the IF board is fed to a cryogenic low noise amplifier (LNA) of 3-13*GHz* bandwidth of a typical noise temperature of about 5 *K*. The pumped, unpumped IV curves and the converted hot&cold IF signal are plotted as a function of bias voltage, at LO frequency of 208 *GHz*, as shown in Fig. 3 (a). The shape of the first photon step indicates that the capacitance of the junction is well tuned at this frequency. The DSB noise temperature as a function of frequency is also plotted in Fig. 3. A DSB noise temperature of 90*K* was obtained in the frequency range of 200*GHz*-245*GHz* with an optimum 70*K* occurring at 208*K*. These measurements were carried out within 4-6 *GHz* IF band.

The preliminary results reported above correspond to the first unilateral finline mixer on a silicon substrate. Better results over a wider IF bandwidth should be possible at these frequency but our results were degraded by harmonics of the LO (feature can be seen on the first photon step in the pumped IV curve). The IF bandwidth of the SIS mixer is limited by the large capacitance of the radial stub, by generating an effective RLC circuit in the IF bandwidth. Optimization of the mixer performance is in progress.



(a) (b)

Fig. 3 (a) The pumped and unpumped IV curve at 208GHz and the hot/cold IF curves against the bias voltage. (b) The noise temperature and the gain measured across the RF bandwidth

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