Broadband Fix-tuned Receivers Using Same Block

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***Abstract*—We present the performances of two sensitive submillimeter receivers operating in distinct bandwidth ranges: 330-540 GHz and 430-660 GHz, by using a unique robust, assembly-friendly, space-qualified fix-tuned mixer block. Only the corrugated horns and SIS devices have been swapped. The Fourier Transform Spectrometry measurements show 50% frequency bandwidth and the uncorrected measured DSB noise temperatures were less than 7 times the quantum limit in both cases.**

***Index Terms*—Fix-tuned mixer block, twin SIS junction, broad bandwidths.**

I. INTRODUCTION

Low noise fix-tuned broad band heterodyne receivers are needed for many projects presently in progress: HIFI heterodyne instrument for space-based telescope Hershel and ground-based interferometer ALMA composed of 64 12-m antennas. Within the framework of HIFI channel 1, i.e 480-640 GHz frequency range, Salez et al [1] have developed a high-performance SIS mixer producing state-of-the-art results; i.e they obtained noise performances better than 3 times the quantum limit over the whole 30% bandwidth. They have used a space-qualified fix-tuned mixer block, in which was mounted an SIS chip fabricated at IRAM [2]. In this paper, we present similar high-performance measurement results at 330-540 GHz, i.e a bandwidth including ALMA band 8, using same robust block. Indeed, HIFI band 1 block has a peculiarity that only the feedhorn section is frequency-band dependant, housing the horn itself, the waveguide transition, the waveguide and the substrate channel, forming a single part (see below). Switching from HIFI band 1 to ALMA band 8 simply meant swapping the corrugated horn and the SIS chip and keeping the rest of the mixer unit identical. In order to compare the performances, we also present FTS and heterodyne measurements obtained with mixer using SIS circuit designed according to Paris observatory fabrication process and operating in HIFI channel 1 band.

II. RECEIVERS

A. Mixer Block

As seen in Fig. 1, our mixer block is divided into two functional components: (a) component including DC supply circuit, the 4-8 GHz IF circuit and the coils, (b) horn component in which is placed the mixer device. It is made up of copper corrugated horn, the waveguide transition, the waveguide and the substrate channel thus forming a single part. The local oscillator (LO) and RF signals are conveyed to the mixer chip via a half-height rectangular waveguide. The mixer device is fabricated on a fused quartz substrate, placed into a channel perpendicular to the waveguide as shown in figure 1-c. The table 1 summarizes the principal horn component dimensions and substrate thickness according to the bands.

TABLE 1 HERE

The waveguide/substrate transition allowing quasi-TEM-mode in microstrip line is realized by a bow-tie antenna whose impedance is real ~ $50 + j0\ \Omega$ over the two frequency bands, thanks to the optimisations using CST-Microwave Studio [3]. Made of the simple plain flat metal part, the backshort, which is into component (a), closes both the substrate channel and the waveguide-end and comes to contact the block (b) between the air-gap of a cryoperm core (see fig. 1-c). In both cases, the microstrip faces the backshort.

FiG. 1 HERE

Consequently, the block manufacturing and assembly are deeply simplified. The undesirable Josephson currents are suppressed by a magnetic field, which is generated by NbTi superconductive wire coiled around a cryoperm core made of a single piece and folded into the proper shape. The IF coupling is provided by an optimized microstrip-to-coaxial 90° transition using a spring bellow, allowing a simple and fast mixer block mounting procedure and avoiding the risks of electrical contact disruption during cool-downs. The principles of this compact ($32x32x40\ mm^3$) and light (67 g) mixer block

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design have been well described in [4]. It is machined by SAP: Sociète Audoise de Précision [5]. As we mentioned above, the mixer block, initially developed for HIFI space instrument, was space qualified by submitting to vibration tests, electromagnetic compatibility (EMC) tests, and thermal cycling tests between 360 K and 4.2 K. It successfully passed all these tests.

B. Detectors and fabrication

The mixer devices are based on double Nb/AlO$_x$/Nb junction tuning circuit [6-7]. We chose an average current density of 10 kA/cm². The devices were initially optimised to operate in ALMA Channel 8 band: 380-500 GHz and HIFI Channel 1 band: 480-640 using same techniques employed for HIFI channel 1 developments [8-10]. The junction areas are respectively 1.3x1.3 µm² with $R_n \approx 10\ \Omega$ and 1.4x1.4 µm² with $R_n \approx 6\ \Omega$. The intrinsic capacitance measured is C_J=81 fF/µm². The voltage gap is ~ 2.82 mV. Their quality defined as the ratio of the subgap current at 2 mV to the normal resistance ratio (R_{SG}/R_n) is ~ 15 average.

FiG. 2 HERE

All SIS devices were fabricated at Paris observatory facility using standard SNEP (Selective Niobium Etching Process) technique [11] based on standard optical lithography process. The 0.2 µm niobium base electrode, the 0.01 µm aluminium, and 0.1 µm upper niobium films are DC sputtered. The tunnel barrier is built by thermal oxidation of the aluminium layer, using pure O_2 before upper niobium deposition. The bow-tie antenna and RF filters were defined by photolithography technique. A 0.25 µm SiO layer was evaporated to isolate the junction's area and to make a dielectric for RF tuning circuits. The photolithography follow-up the lift-off of 0.35 µm counter-electrode niobium allows to connect the junctions and to define the upper electrode of the RF tuning circuits. It was DC sputtered. Finally, a 0.2 µm gold film was evaporated in order to obtain the electrical contact.

III. RESULTS

The SIS mixer is cooled down to 4.2 K in a cryostat. The IF signal is amplified by a 4-8 GHz cryogenic HEMT preamplifier. A current of less than 10-mA was sufficient to produce a flux of two quanta ($2\Phi_0$), allowing the quasi-total suppression of Josephson effect. The IF matching is provided by a 50-Ω microstrip line on an alumina board, contacting a coaxial SMA plug at 90°. The local oscillator signals were provided by two solid-state sources which cover the 385 to 500 GHz range. On their quasioptical path, RF and LO signals encounter a 13-µm mylar beam splitter, a 25-µm mylar cryostat window, a 250-µm Zitex infrared filter and two cold elliptical mirrors before arriving at the mixer feedhorn.

A. Fourier Transform Spectroscopy

Direct detection responses, obtained by FTS measurements, reveal a 50 % relative bandwidth in both cases as shown in Fig. 3. The measurements were made without vacuum environment. We note the water transitions at 385 GHz and 557 GHz, as two clear absorption features.

B. Heterodyne measurements

Fig. 4-c and 4-d show the uncorrected DSB receiver noise temperatures measured over a 385-500 GHz and 490-700 GHz frequency range. Below 385 GHz, the measurements were not possible due to lack of LO source operating at these frequencies. DSB receiver noise temperature is measured by standard Y-factor method: $Y=P_{hot}/P_{cold}$ where P_{hot} and P_{cold} are respectively the measured IF output power using hot (298 K) and cold (170K) blackbody sources as the input signal. The IF output power versus DC bias voltage for both load temperatures are shown in Fig. 5.

FiG. 3 HERE

FiG. 4 HERE

For the lower band, the noise temperatures are relatively homogeneous over the whole bandwidth.The lowest noise temperature is 95 K measured at 474 GHz and the highest is 142 K at 385 GHz. For the higher band, the DSB noise temperatures were below 160 GHz expect at 641 GHz where we measured 190 K. This increase is due to the very low output power of our LO chain at this frequency. The quasioptical contribution was estimated around 40 K using the intersecting lines technique [12]. The IF noise is about 15 K, as deduced using the shot noise in the twin SIS junctions as a calibrator. In this case, the corrected noise temperatures; i.e subtracting the quasioptical loss contribution, are equivalent to about 3 times the quantum limit.

FiG. 5 HERE

IV. CONCLUSION

We have measured two fix-tuned mixers designed to operate in two different band frequencies: 385-500 GHz and 480-640 GHz, using the same mixer unit. It was possible thanks to judicious concept of the mixer block where only the corrugated horn is swapped. The FTS measurements showed a relative bandwidth of 50% in both cases. The uncorrected DSB noise temperatures are between 95 and 142 K for lower band and between 97 -190 K for the higher band at 4.2 K. In addition, we expected similar performances for any wide band from 200-800 GHz using the same Nb process, by simply manufacturing band-specific front sections consisting each of the adequate corrugated feedhorn, waveguide and SIS device.

ACKNOWLEDGMENT

This work has been funded by the Centre National de la Recherche Scientifique (CNRS)-Institut National des Sciences de l'Univers (INSU). The french space agency CNES has funded the HIFI channel 1 project and has co-funded with CNRS this development. We would like to thank G. Beaudin, J-M. Lamarre, Y. Viala and P. Encrenaz for their continued support and I. Peron and K.F. Shuster for their fruitful discussions.

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TABLE I

PRINCIPAL HORN COMPONENT DIMENSIONS

	ALMA Band 8	HIFI Band 1
Substrate thickness (µm)	60	50
Channel width (µm)	160	130
Rectangular Waveguide (µm)	500x125	400x100

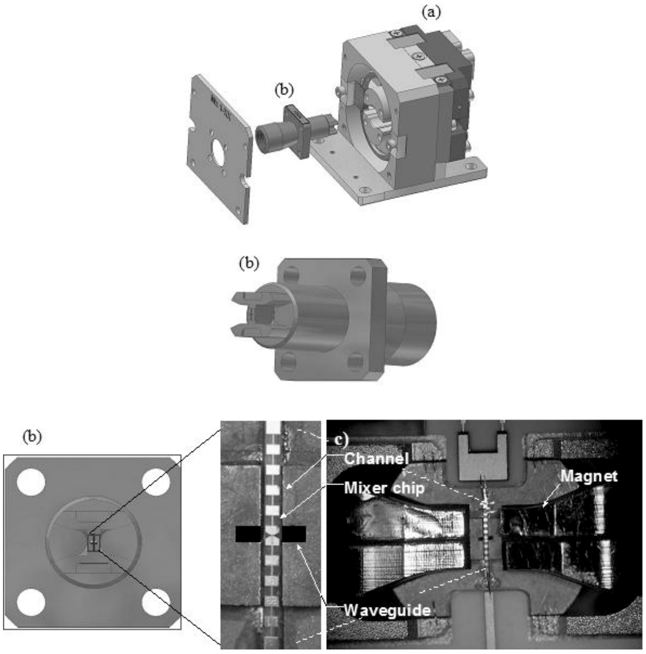

Fig. 1. Views of our mixer block: (a) component including DC supply circuit, the 4-8 GHz IF circuit and the coils, (b) horn component made up of corrugated horn, the waveguide transition, the waveguide and the substrate channel . View (c) shows mixer chip placed into substrate channel perpendicular to the waveguide and the magnet.

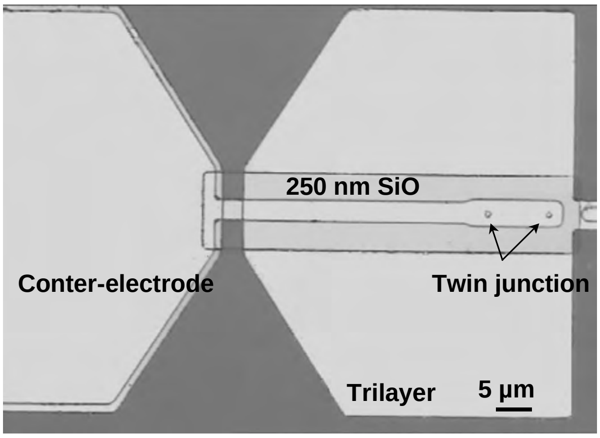

Fig. 2. Optical microscope image of twin parallel. The Nb/AlO$_x$/Nb SIS junctions are 1.3x1.3 µm^2.

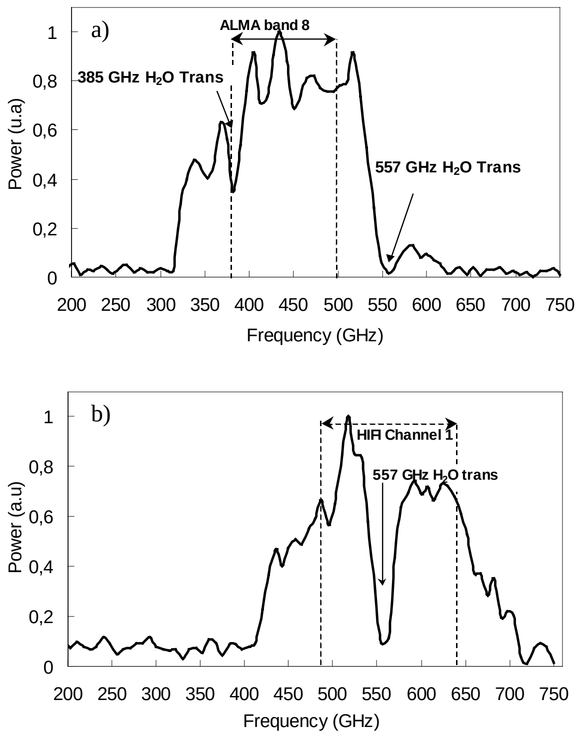

Fig. 3. Direct detection response of two mixers using same mechanical block by swapping only the horns. The measurements were made without vacuum at 4.2 K.

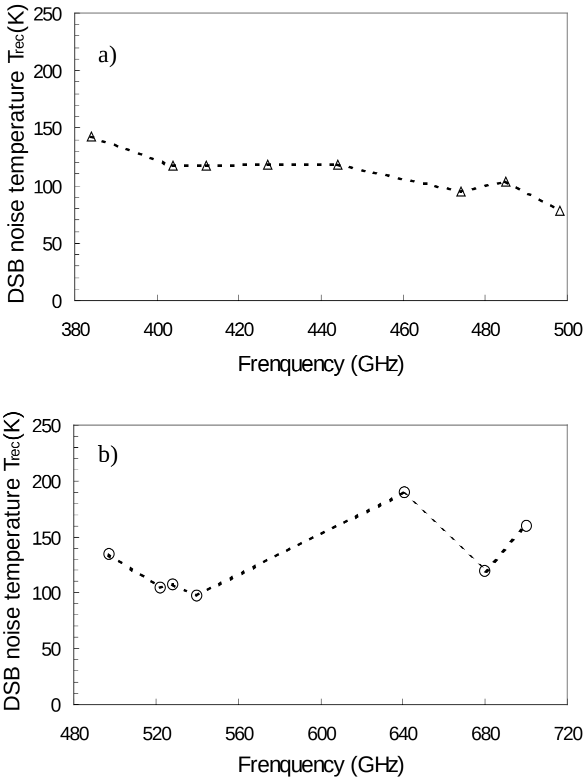

Fig. 4. Uncorrected DSB noise temperatures receiver versus frequency of two mixers measured at 4.2 K.

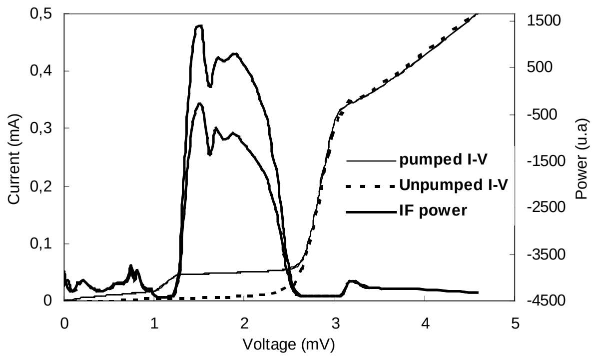

Fig. 5. IF output powers, unpumped and pumped I-V curves versus voltage bias for ALMA device at 385 GHz using hot (298K) and cold (170K) loads.