Performance of a wide IF SIS-mixer-amplifier module for ALMA band 8 (385-500 GHz)

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Abstract— This paper reports the receiver performance based on a low-noise heterodyne module with very wide intermediate frequency (IF) bandwidth in the radio frequency range 385–500 GHz. The module integrates a superconductor-insulator-superconductor (SIS) mixer with a 3–21 GHz low-noise preamplifier. We utilize high current density junctions for the SIS mixer to achieve good matching conditions between the SIS junction and the amplifier, and to maintain the IF performance over the designed local oscillator (LO) frequencies. The measurement results of the receiver using the heterodyne module demonstrate a typical noise temperature of 70-80 K over 3–18 GHz, at LO frequencies of 400–480 GHz.

INTRODUCTION

At NAOJ, we are carrying out a feasibility study for increasing the intermediate frequency (IF) bandwidth of SIS receivers at submillimeter wavelengths. In the Atacama large millimeter/submillimeter array (ALMA) project [1], enhanced instrument capability that would offer multiline observations without changing the local oscillator (LO) frequency, is one of the targets in future development programs [2], [3]. Most heterodyne receivers are equipped with a cryogenic isolator inserted between SIS mixer and low-noise amplifier. Using this configuration, excellent performance has been demonstrated but IF bandwidths are usually limited to 4-12 GHz. This is because for a passive component, e.g. the isolator, it is in general difficult to simultaneously obtain low reflection and insertion losses over a bandwidth exceeding one octave. In order to achieve a wider IF performance, a possible solution is to omit the isolator and to directly integrate SIS mixer and amplifier by making a short connection between them. However, there are several technical challenges such as impedance matching, thermal isolation and packaging.

SIS-MIXER-AMPLIFIER MODULE ASSEMBLY

Fig. 1 shows the mixer block and cryogenic low-noise amplifier. We used an SIS mixer chip similar to the one used for ALMA band-8 cartridges (radio frequency RF: 385-500 GHz) with only minor modifications in the tuning circuit to accommodate higher current density junctions with j_c=25-30 kA/cm^2 [4]. We note that the circuit was not optimized for wide IF bandwidth operation.

The 60 μm x 120 μm x 2.3 mm SIS mixer chip is mounted into the chip slot across a rectangular wave guide. Bonding wires are used to connect ground and IF pads to the microstrip line at the input of the cryogenic IF amplifier which itself is fixed by screws onto the mixer block, see Fig. 1. This configuration allows us to remove the amplifier and easily connect another component directly to the IF output of the SIS mixer. A superconducting magnet coil (NbTi) is placed behind the SIS mixer chip to suppress the Josephson current [5].

We used a 3–21 GHz cryogenic amplifier manufactured by Low Noise Factory with a typical noise temperature of 5 K and gain of 35 dB [6]. The amplifier input circuit incorporates a microstrip-based matching circuit for wideband noise and impedance matching to a source impedance of 50 Ω, with a typical return loss of −10 dB, and a bias-T circuit for 4-terminal sensing to apply bias voltages to the SIS junctions. A K-connector is implemented at the output of the module.

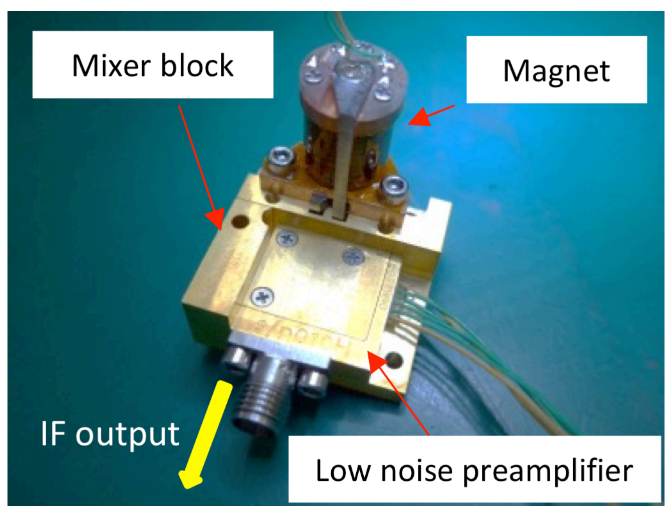

Fig. 1. Photograph of the SIS-mixer-preamplifier module. A drop-in type low-noise cryogenic amplifier is fixed by screws onto the mixer block. The RF signal and the LO power are injected through a waveguide from the back of the mixer block.

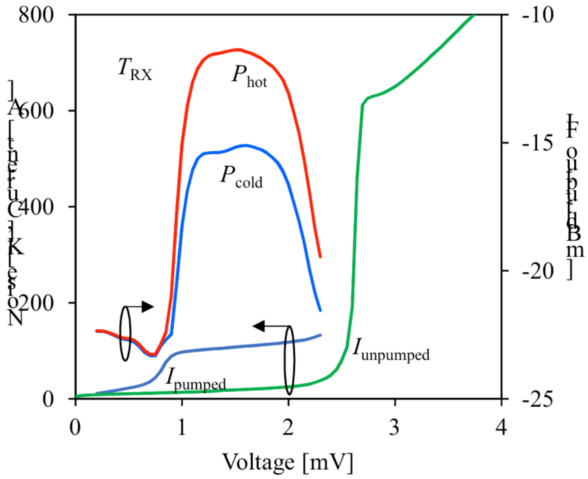

Fig. 2. Heterodyne response of the wide IF bandwidth receiver using the SIS-mixer amplifier module at an LO frequency of 440 GHz. The output power and double sideband (DSB) receiver noise temperature were measured with a power meter.

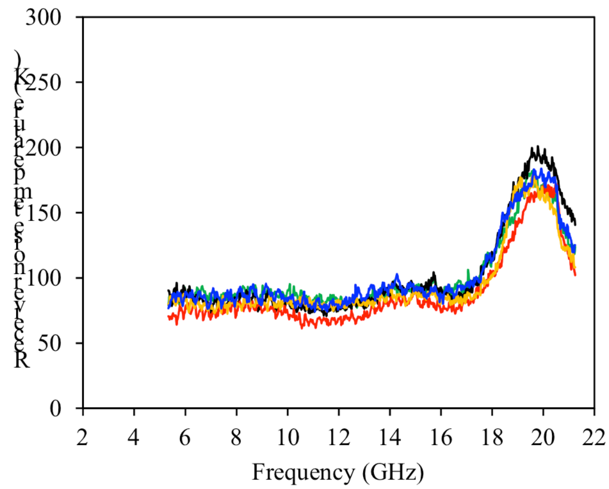

Fig. 3. DSB receiver noise temperature as a function of the IF at LO frequencies of 400 (green), 420 (black), 440 (red), 460 (yellow), and 480 GHz (blue).

Receiver Noise temperature

The RF and IF receiver performances using the SIS-mixer-preamplifier module was evaluated with a measurement setup covering RF: 385–500 GHz and IF: 0.01-26.5 GHz. The receiver output power within the IF band, and power spectrum as a function of the IF were measured using a power meter and spectrum analyzer, respectively. The receiver noise temperature measurement was based on the standard *Y*-factor method with room temperature (295 K) and liquid-nitrogen-cooled (77 K) blackbody loads.

Fig. 2 shows the measured *I-V* characteristics of two parallel connected $Nb/AlN_x/Nb$ junctions, 0.8 μm in diameter, fabricated at the National Astronomical Observatory of Japan [7]. The critical current density of the SIS junctions was ~45 kA/cm^2. Even though this is considerably higher than the target value, the RF matching circuit still yields reasonably good coupling to the junctions. Fig. 2 also shows the heterodyne response of the wide IF receiver measured at an LO frequency of 440 GHz. The IF responses to hot and cold loads showed a *Y*-factor of 3.8 dB at a bias voltage of 1.4 mV, which corresponds to a double sideband (DSB) receiver noise temperature of 74 K. The dynamic resistance estimated from the LO-pumped *I-V* characteristic was 55 Ω at the chosen bias point, which is close to a 50-Ω standard impedance.

Fig. 3 summarizes measurement results of the DSB receiver noise temperature as a function of the IF at LO frequencies of 400–480 GHz. The measured noise temperature was typically 70-80 K and below 100 K, over 3–18 GHz. The variations are almost independent of the LO frequency. The noise temperature performance over 3–18 GHz is comparable to mass-produced ALMA band-8 receivers with an IF of 4–8 GHz [8]. However, it can be seen that the receiver performance deteriorates above IF 18 GHz at all LO frequencies. This is attributed to the IF matching conditions between SIS mixer and amplifier.

Detailed characterization

In order to understand the degradation above 18 GHz and to further improve the performance, the module has to be characterized in detail. However, it is not straightforward to estimate how the components behave when they are integrated. The design of our module permits separate characterization of its constituents, and we have studied SIS mixer and IF amplifier using *S*–parameter measurements at microwave frequencies. The results and analysis have been included in an extended paper submitted to IEEE Transactions on Terahertz Science and Technology.

Acknowledgment

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