Development of the 787-950 GHz ALMA Band 10 Cartridge

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***Abstract*—We are developing the Atacama Large Millimeter/Submillimeter Array (ALMA) Band 10 (787-950 GHz) receiver cartridge. The double-side-band (DSB) mixer consists of a corrugated feed horn, a full-height waveguide mixer block and a Nb(Ti)N-based superconductor-insulator-superconductor (SIS) mixer chip. The IF system uses a 4-12-GHz cooled low-noise InP-based MMIC amplifier and a 4-12-GHz isolator. Heterodyne sensitivity tests showed the mixer noise temperature of about 200 K in the 800 GHz band at an operating temperature of 4 K. This result is comparable to the state-of-the-art mixer performance at this frequency range.**

I. Introduction

THE Atacama Large Millimieter/Submillimeter Array (ALMA) is a gigantic radio telescope array consisted of up to sixty-four 12-m antennas and the Atacama Compact Array (ACA) system (four 12-m antennas and twelve 7-m antennas), under construction on an Andean plateau at 5,000 m above sea level in Chile [1]. ALMA is a partnership among Europe, Japan and North America, in cooperation with the Republic of Chile. Taiwan is also contributing to ALMA as a partner of Japan. ALMA telescope cover the frequency range from 30 to 950 GHz, which is divided into 10 frequency bands. Receivers of each band are requested to achieve severe specifications of ALMA, e.g., state-of-art sensitivity, efficient optical coupling to ALMA antenna, high stability, and so on. The band 10 will operate in the highest frequency range from 787 to 950 GHz where conventional niobium (Nb) technologies are not applicable for tuning of superconductor-insulator-superconductor (SIS) mixers because of the large losses due to the onset of the pair-braking above the superconducting gap frequency of about 700 GHz. It is also the most difficult band to achieve small mechanical tolerances caused by the extremely short wavelengths.

In order to develop Band 10 cartridge, we have established a lot of base-technologies at terahertz frequencies in component level, which are Nb(Ti)N SIS junctions [2], waveguides [3], optics [4], and so on. In addition, test equipments such as near-field beam scanner have been developed to characterize receiver performance [5]. Based on these state-of-the-art technologies, a prototype Band 10 cartridge has been designed, and now is being produced. We will present our current status of Band 10 cartridge development.

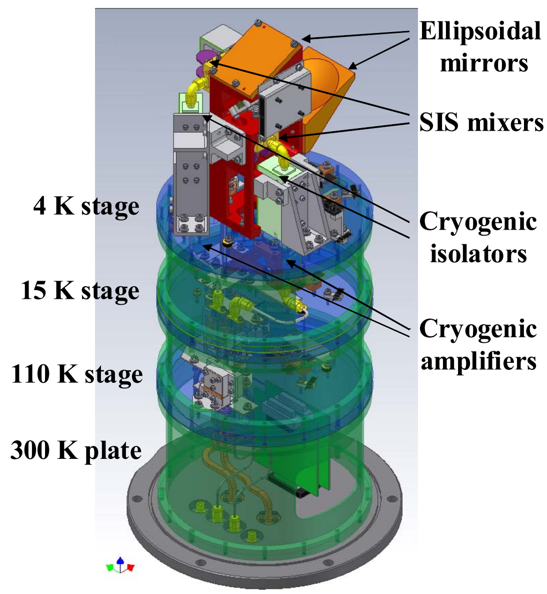

Fig. 1. A design of the ALMA Band 10 cartridge.

II. Cartridge Design Overview

Fig. 1 shows a three dimensional view of the entire Band 10 cold cartridge. The cartridge consists of three cooled stages with operating temperatures of 4 K, 15 K and 110 K, and a room-temperature base-plate which acts as the vacuum seal. The stages are supported by thermally insulating fiber-grass cylinders [6]. Cryogenic fixed-tuned x9 (x3 by x3) multipliers are put in the cartridge for providing Local Oscillator (LO) power to SIS mixers. Heat sinks for the LO waveguides, coaxial cables and wiring, are on the 110 K stage. The only components on the 15 K stage are the heat sinks for the LO waveguide, coaxial cables and wiring. The 4 K stage has two ellipsoidal mirrors, a wire-grid, two horns, two mixer blocks integrated with a waveguide coupler, two isolators, two IF amplifiers, and heat sinks for the LO waveguides, coaxial cables and wiring.

III. Key Component Developments

A. Optics

The ALMA band 10 front-end optical configuration has been designed and theoretically assessed by means of accurate Physical Optics electromagnetic analysis. The optical design

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has been made on the basis of the following considerations: mechanical compactness, low center of mass, beam clearance of a least 5 beam waists, frequency independent coupling with the Cassegrain antenna, and secondary illumination taper of -12 dB. The LO power will be injected to the SIS mixer by a waveguide coupler, which simplify the optical design.

The beam coming from the telescope passes through the vacuum window and infrared filters. Two ellipsoidal mirrors are used to match the incoming beam and the corrugated feed horn. After reflecting the beam by the pair of the mirrors, the two orthogonal polarizations are split by a free-standing wire grid. Then each beam enters the corresponding feed horn. The optical components consisting of the mirrors, wire grid and feed horns are mounted to the 4-K optics support structure made from one Aluminum block to reduce alignment errors.

The corrugated horn which is one of the critical components in optics has been made by an electro-forming and a direct machining to mitigate risks in production. Both horns have shown good beam characteristics, which were measured by our near field beam scanner at terahertz frequencies.

B. *Waveguides*

We have produced Band 10 waveguide components such as couplers by utilizing recent direct machining technologies achieving very small sizes down to several tens of microns. Fig. 2 shows a photograph of a 10-dB directional coupler made of copper at Band 10 frequencies. The waveguide was gold-plated for corrosion protection. The insertion loss at room temperature was measured by our vector network analyzer at terahertz frequencies. Typical values of S21 and S42 for the 30-mm long waveguides were respectively -3.5 dB and -14 dB at Band 10 frequencies. Assuming a typical ohmic loss of gold at room temperature, these results are reasonable, i.e., the 10-dB coupler was well produced. Since measured residual resistivity ratio (RRR) of the 1-um-thick plated-gold was about 10, we can expect the waveguide loss of about 0.04 dB/mm at 4 K, according to a simple theoretical calculation. This value should not result in significant RF loss in the waveguide.

C. *SIS Mixers*

We are developing three types of SIS mixers which employ Nb(Ti)N technology, as shown in Fig. 3. These mixers are being evaluated by our receiver test system. The cooled IF amplifier used in the system has an outstanding performance showing the noise temperature of below 5 K in the 4-12 GHz frequency band, developed by S. Weinreb of Caltech. We also prepared an all-solid-state fixed-tuned LO source (similar to the ALMA LO system) consists of a microwave synthesizer, a W-band active multiplier, an 88-105-GHz high power amplifier (100 mW output), and a x9 multiplier. The output power of the LO unit is more than enough power to pump SIS mixers for whole band 10 frequency range. Fig. 4 shows our latest mixer noise temperatures at the operating temperature of 4 K. Also shown are ALMA spec. of 230 K for 80% bandwidth and 344 K for full band. The minimum noise temperature below 200 K has been achieved across 4-12-GHz IF band.

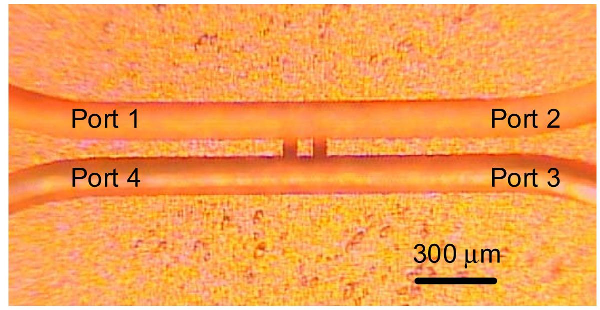

Fig. 2. An optical micrograph of a 10-dB directional coupler at Band 10 frequencies.

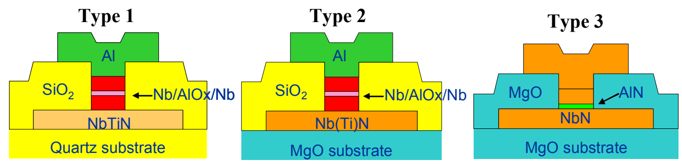

Fig. 3. Three candidates for the ALMA band 10 mixer device.

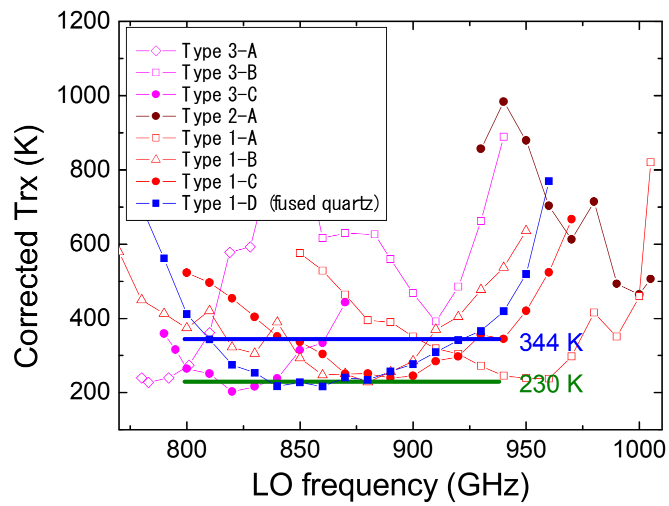

Fig. 4. Summary of the latest band 10 mixer performance.

IV. Acknowledgement

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