

Design and Development of ALMA Band 4 Cartridge Receiver

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Abstract— This paper describes the design and development of the ALMA Band 4 cartridge receiver. Band 4 is one of the ten bands that will form the ALMA Front End Receiver. It receives radiation in the 125-163 GHz frequency range in two orthogonal polarizations and down-converts the sideband separated signals to intermediate frequencies between 4 and 8 GHz.

I. INTRODUCTION

The Atacama Large Millimeter/Submillimeter Array (ALMA) is an international collaboration between Europe, Japan and North America, in cooperation with the Republic of Chile with its full-operation expected in 2012 [1]. Taiwan is also contributing to ALMA as a partner of Japan. ALMA will be located on the Chajnantor plain of the Chilean Andes in the District of San Pedro de Atacama, 5,000 meters above sea level. The ALMA receiver system will cover all the available atmospheric frequency windows between 30 GHz and 950 GHz. The range shall be covered in 10 bands with HEMT or SIS devices. The receiver should be modular so that one easy to install self-contained receiver should cover that one particular frequency band. These self-contained receivers are known as "cartridges". The development and production of the Band 4 cartridge receivers is one portion of the Japanese in-kind contribution to ALMA.

II. RECEIVER OVERVIEW

ALMA Band 4 will operate in the 125-163 GHz frequency band, which is 26 % bandwidth to the center frequency of 144 GHz. A layout of the Band 4 cartridge receiver and a photograph of the assembled cartridge are shown in Fig. 1 and Fig. 2, respectively. Band 4 receivers are made on the small 140mm diameter cartridges developed by Rutherford Appleton Laboratory (RAL). It is a dual polarization receiver, which uses an orthomode transducer (OMT) as a polarization splitter. The cartridge consists of three stages (at operating temperatures 4, 15, and 110 K) and the base-plate (which acts as a vacuum seal) at 300 K, with GFRP 10 spacers between them. The 110 K stage has the LO doublers mounted on it and heat

sinks for the LO waveguide, coax cables and wiring. The 15 K stage has only heat sinks for the LO waveguide, coax cables and wiring attached. The 4 K stage has the Corrugated horn, OMT, optics support structure, sideband-separating SIS mixer units, Cryogenic Isolators, Cryogenic HEMT Amplifiers, and heat sinks for the LO waveguide, coax cable and wiring attached.

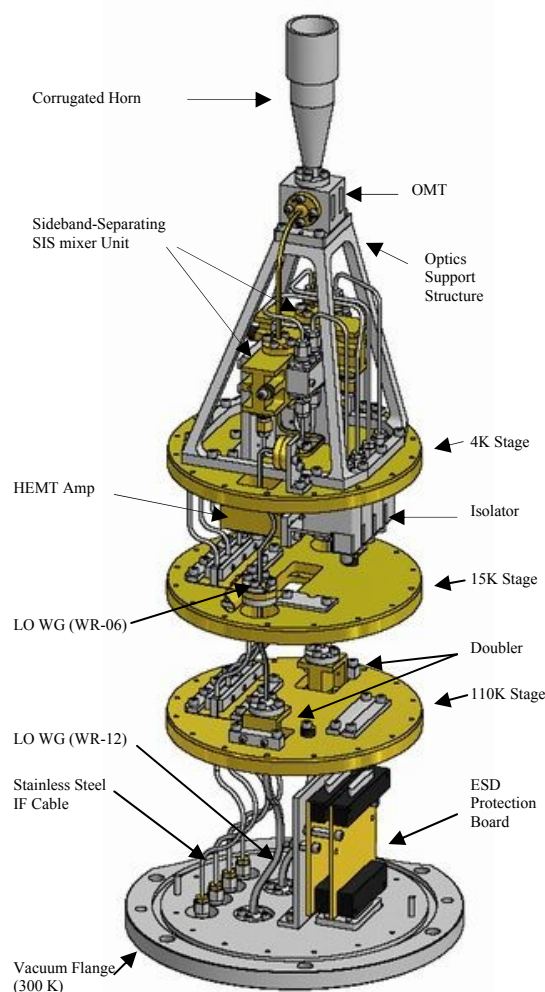


Fig.1 Layout of the ALMA Band 4 cartridge receiver. DC wire harnesses are not illustrated

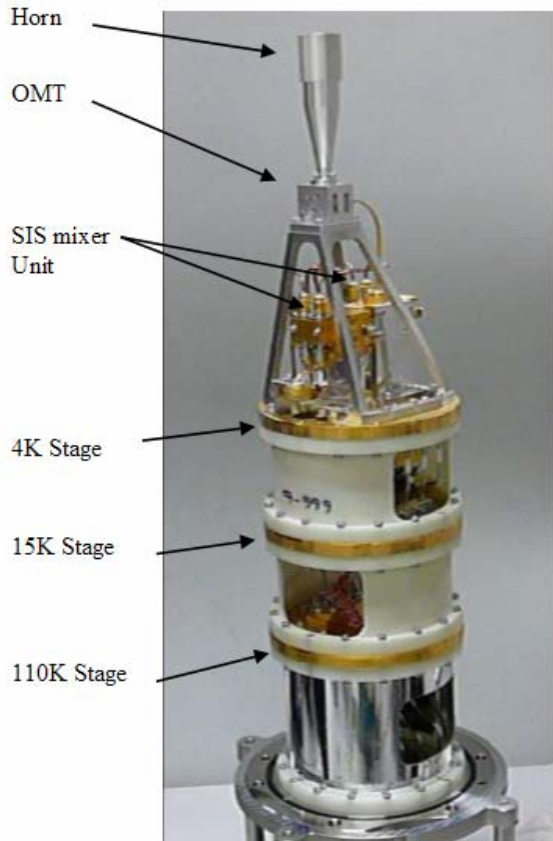


Fig.2 View of complete cartridge

A. . Optics Scheme

The Band 4 optics design was done by K. Kimura and H. Ogawa, and is shown in Fig. 3. Their work was in close collaboration with the optics calculations of C-Y. Tham [2]. There is not enough room inside the cartridges to have cold optics as for bands 5 and above. The system chosen is to have ambient temperature mirrors. The beam coming from the telescope is incident on a flat mirror, which reflects the beam out to an elliptical mirror and then the beam is focused down into the cryostat onto the horn. It is a dual polarization receiver, which uses an orthomode transducer (OMT) as a polarization splitter. An OMT is a passive waveguide device that separates the signal received by the feed horn into its two orthogonal linearly polarized components. Band 4 OMT has been designed to make the two outputs orthogonal to each other as required for the cartridge construction.

The Band 4 corrugated horn was designed by K. Kimura [3]. It is a conventional corrugated horn with a total length of 94 mm and horn diameter of 28 mm. The slot width and depth of the corrugation are 0.34mm and 0.8 - 0.52mm (depending on position), respectively. This corrugated horn was fabricated using NC machining suited for the series production process.

A. Mixing Scheme

To meet the technical specification of the ALMA Band 4 receiver, we developed a sideband-separating SIS mixer.

The design uses two double sideband (DSB) SIS mixers in a single mixer block containing waveguide hybrids, and LO power dividers and couplers. Approximately -20 dB of the LO power is coupled to each of the building block mixers. The sideband separation results from two 90 degree hybrids: One is an RF hybrid in the mixer block and the other is an IF hybrid. There are no mechanical tuners.

C. LO Scheme

For each polarization channel cryogenic doublers (made by Virginia Diodes) is mounted on the 110 K stage. The doubler is pumped by a microwave signal in the range of 66.5 to 77.5 GHz which corresponds to an output frequency range of 133 to 155 GHz.

The room temperature driver for the LO system is made at National Radio Astronomical Observatory (NRAO) in Charlottesville. It is based on a YIG oscillator, its signal is multiplied $\times 3$ and amplified by a power amplifier. Details of similar system can be found in [4].

D. IF Scheme

A Band 4 cartridge uses GaAs-Based 3-stage Cryogenic amplifiers via a cryogenic isolator, to amplify IF signal between 4-8 GHz from two 2SB mixers of dual polarization.

At room temperature, 4 dB gain-slope-corrected amplifiers are used to compensate for frequency dependent cable losses and mixer gain variation.

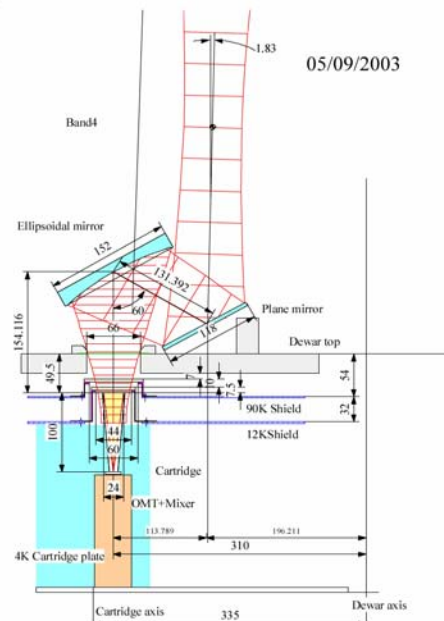


Fig.3 Design of the Band 4 Optics

III. DEMONSTRATED COMPONENTS PERFORMANCE

A. Integrated 2SB mixers

The cartridge contains two sideband-separating SIS mixers. The basic design of the Band 4 sideband-separating SIS mixer is the same as the scaled model described by Asayama et al. [5]. To couple the LO and RF signals into a quasi-TEM-mode microstrip line, a bow-tie waveguide probe based on a 200 μm -thick quartz substrate was adopted. The mixer device was a parallel-connected twin-junction (PCTJ) [6]. 1.8 x 1.8 μm size SIS junction of a current density of 3 kA/cm^2 ($\omega\text{RnCj} = 3.6$) were adopted. The normal-state resistance of the SIS junction is about 20 Ω and the junction's specific capacitance is estimated to be 60 $\text{fF}/\mu\text{m}^2$.

A quarter wavelength impedance transformer made of superconducting stripline was integrated with the SIS junctions on the mixer device. A photograph of the device configuration on the mixer device is shown in Fig. 4. The upper conductor of the stripline was extended from the feed point in the center of the waveguide to the SIS junctions, where the RF choked electrode was used as a ground plane. To reduce source impedance further, a mirror symmetrical circuit pattern about the bisection plane in the center of the waveguide was introduced. Using this method, the source impedance seen from the mixer device is only half of the feed point impedance.

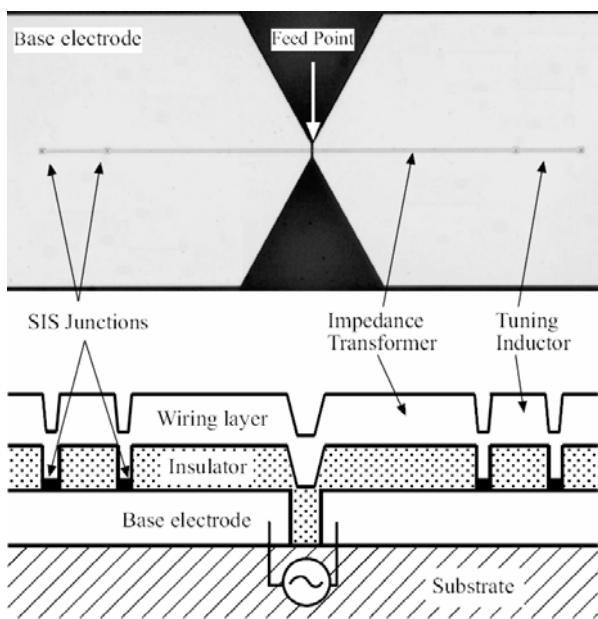


Fig.4 Photograph (upper) and schematic (lower) of a PCTJ device.

A photograph of the assembled 2SB mixer block with IF hybrid coupler is shown in Fig. 5. The waveguide is standard WR-06 (1.65x0.825 mm). The split-block waveguide devices are manufactured from tellurium copper and then gold plated.

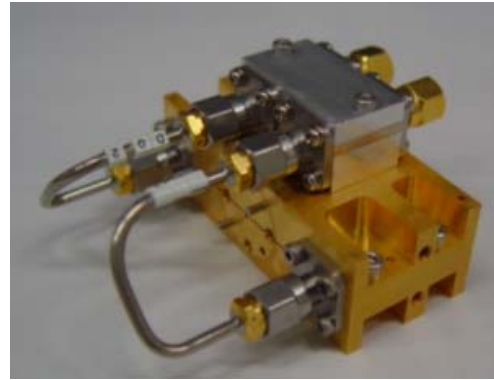


Fig.5 Photograph of the assembled 2SB mixer block with IF hybrid.

The measured receiver noise temperatures and image rejection ratios are plotted in Fig. 6. Those noise temperatures were corrected for the contribution of the image sideband. For measuring image rejection, the method presented by Kerr et al, was used [7]. The measured results shown in Fig. 6 demonstrate that the noise temperature is below 45 K and the image rejection ratio better than 10 dB throughout the RF band. Although the noise temperature tends to increase at the higher IF frequency in some cases, the results meet the ALMA specifications.

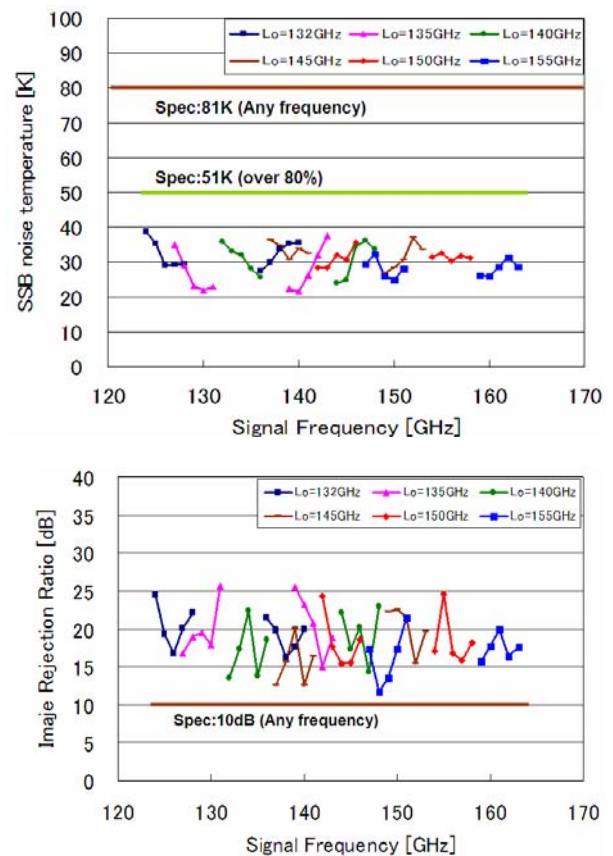


Fig.6 Measured SSB noise temperature (top), and image rejection ratio (bottom) for the integrated 2SB mixer.

B. Beam performance

Beam pattern of Band 4 corrugated horn and warm optics assembly was measured using a NSI Model 200V-3x3 Vertical Planar Near-field System [8]. Fig. 7 shows the block diagram of a cold beam pattern test setup. A view of the measurement setup is shown in Fig. 8.

Warm optics assembly was mounted on test dewar top plate. An ALMA Band 4 window was used on the test dewar. However, due to the mechanical conflict between the horn and IR filter position, IR filters were not installed in test dewar.

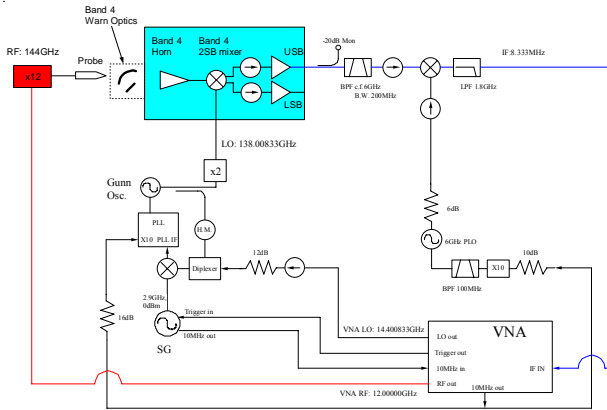


Fig.7 Block diagram of a cold beam pattern setup

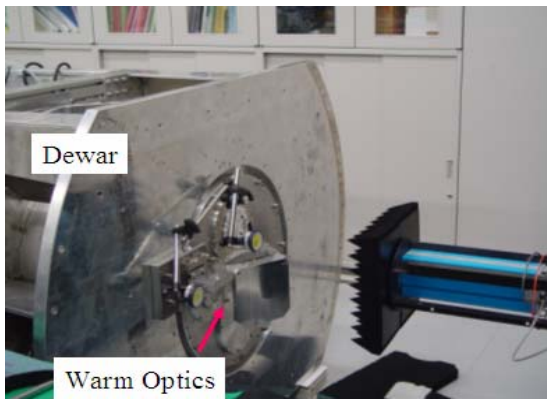


Fig. 11 Band 4 cold beam pattern test setup

2-D plots of the co-polar beam patterns at far-field are shown in Fig. 9. The peak of cross polarization is lower than the co-polar one by 25 dB. Cross sectional view of the co-polar far-filed beam patterns measured and simulations are shown in Fig. 10. As can be seen in these plots, the measurement results are in reasonable agreement with the design. The measured co-polar beam patterns are consistent with the simulation down to a level of -25 dB.

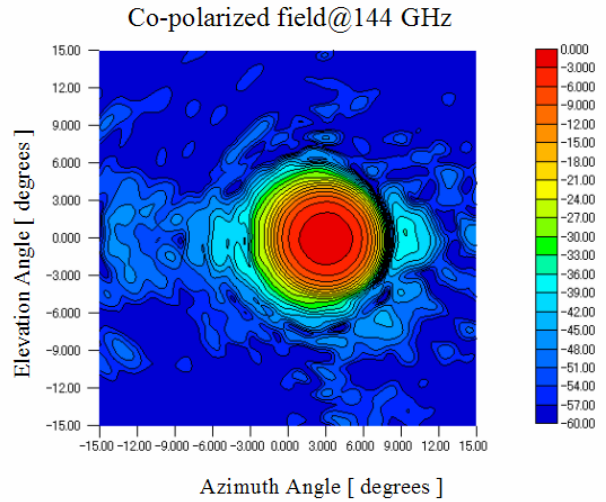


Fig.9 Far-field Beam pattern of Band 4 cold beam pattern (Warm optics + window + horn) at 144GHz. Contours are every 3 dB.

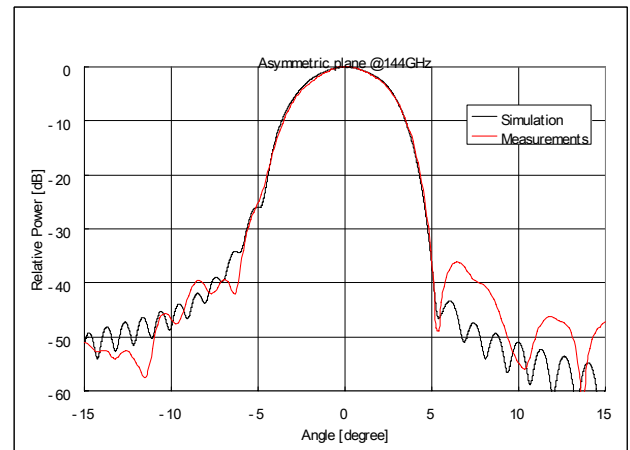
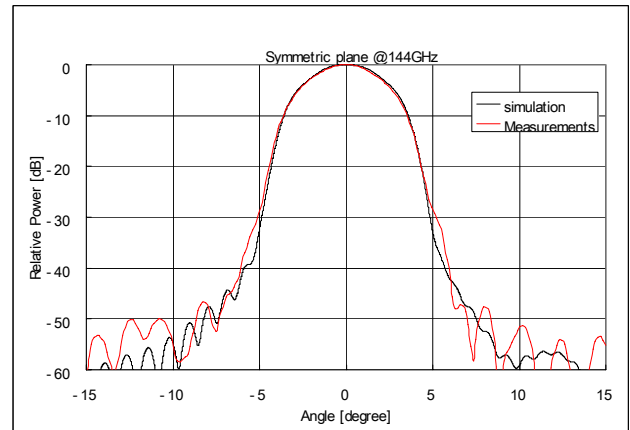


Fig.10 Cross sectional views of co-polar beam patterns in the symmetric and asymmetric plane along with the beam axis. Red lines indicate measured beam patterns. Black lines are the physical optics calculation by M. Sugimoto.

C. 2 MM BAND ORTHO-MODE TRANSDUCER

The double ridged waveguide-based design was adopted for Band 4 OMT and has been designed and developed. The double ridged section was designed referring to that described by Dunning [9]. Fig. 11 shows the wire frame model of the complete orthomode transducer. Signals split by the OMT junction are recombined using a power combiner, implemented using the E-plane Y-junction. The combiner was designed referring to ALMA memo #381 [10].

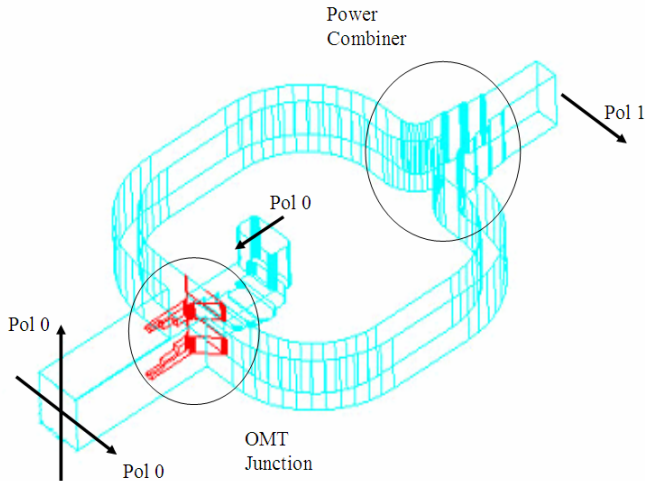


Fig. 11 Wire frame model of the waveguide structure of the OMT.

Photograph of the 2 mm OMT Split-Block is shown in Fig. 12. The split-block was designed referring to that described by Narayanan et al [11] and MOOREY et al [12]. The long oval waveguide for the vertical (main arm) polarization was fabricated using NC machining. Machining errors of the OMT were measured with the contactless laser measurement system. The RMS machining errors were better than 20 microns.

Measurements were performed at room temperature using an Agilent vector network analyzer (WR-06: 110 to 170 GHz). Fig. 13 through Fig. 14 show measured insertion losses, return losses of Seven OMTs. Seven Band 4 OMTs show the return losses better than 18 dB, insertion losses of less than -0.5 dB. Cross polarization couplings of better than -28 dB across the 125 – 163 GHz.



Fig. 12 Split-block view (Top) and assembled Band 4 OMT block (Bottom)

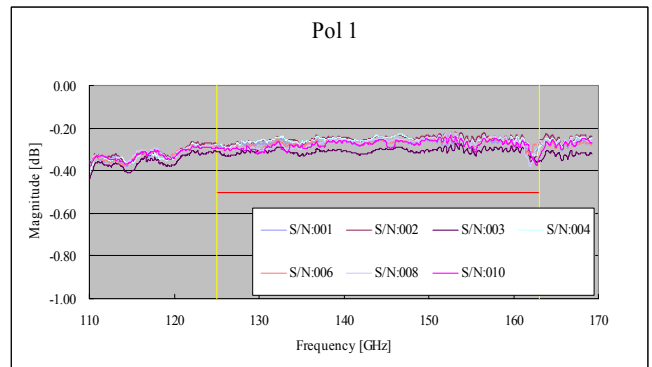
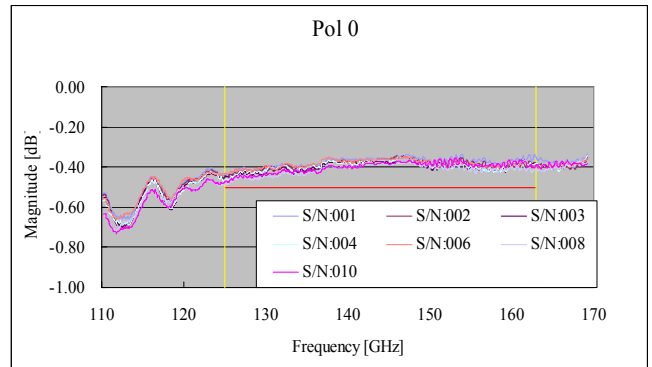


Fig. 13 Measured insertion loss of Band 4 orthomode transducer

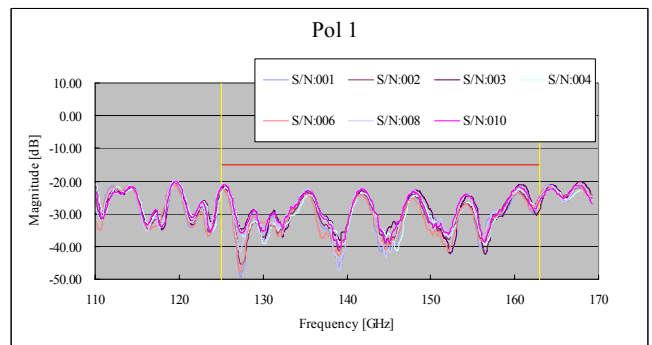
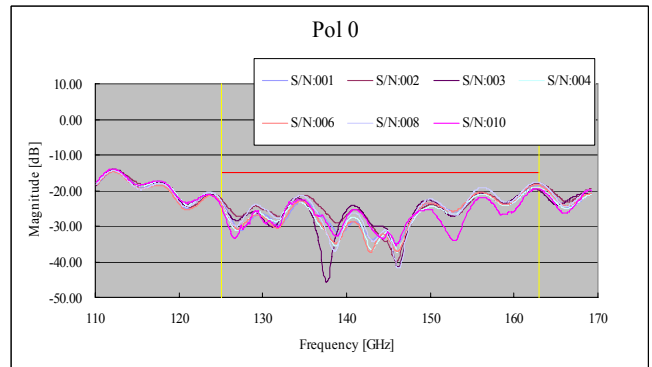


Fig. 14 Measured return loss of Band 4 orthomode transducer

IV. MEASUREMENTS OF THE PROTOTYPE CARTRIDGE

The overall receiver noise temperatures of the Band 4 prototype cartridge averaged over the IF band of 4-8 GHz are plotted in Fig. 15. The noise temperatures were corrected for the contribution of the image sideband at IF center frequency 6 GHz. The noise performance includes the contribution of the vacuum window, IR filters, and IF amplifier chain. The measured single-sideband (SSB) receiver noise temperatures meet the ALMA noise temperature specification.

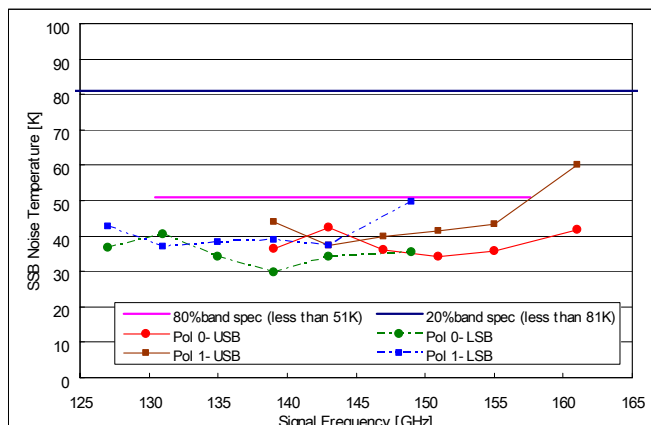


Fig.15 SSB noise temperature of ALMA band 4 2SB mixer with averaging over the IF band of 4 – 8 GHz. Those noise temperature were corrected for the contribution of the image sideband at IF center frequency 6 GHz.

CONCLUSIONS

In conclusion, we have been developing the ALMA Band 4 cartridge receiver. To meet the technical specification, we have developed corrugated horn, OMT, 2SB SIS mixer, etc. The prototype cartridge results is promising that the Band 4 cartridge will meet the ALMA technical specification.

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