S-parameter Measurements of ALMA Band 2 Orthomode Transducer using Cryogenic System at Room Temperature

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***Abstract*— This paper describes a verification of our cryogenic measurement system of insertion and return losses for the ALMA Band 2 orthomode transducer (OMT). This system consists of a vector network analyzer, two frequency extenders in 67-116 GHz band, vacuum feedthroughs (FTH), and thermal insulation waveguides (TIWG). In this cryogenic system, the waveguides and their interfaces including the FTHs and TIWGs significantly affect the accuracy of the *S*-parameter measurement. Thus, we have attempted to perform *S*-parameter calibration of the measurement system at the output port of TIWGs. When measuring the *S*-parameters under cooling with this system, long time interval is required between each calibration and measurements, which causes the drift of the extender characteristics to degrade the measurement accuracy. Therefore, in this study, we adopted a method to perform the *S*-parameter calibration at the input/output ports of the frequency extenders in every calibration and measurement step. To verify our calibration method, we compared two different *S*-parameter measurements of the OMT at room temperature between the direct method and our method performed at reference planes inside the cryostat. The result confirmed that our measurements were consistent except on the low-frequency side.**

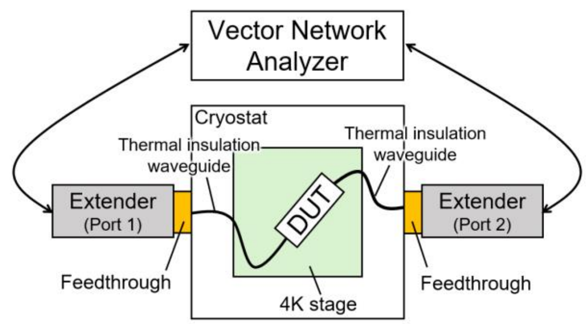
***Keywords*— ALMA, cryogenic, measurement system, orthomode transducer, S-parameter, waveguide, W-band.**

I. Introduction

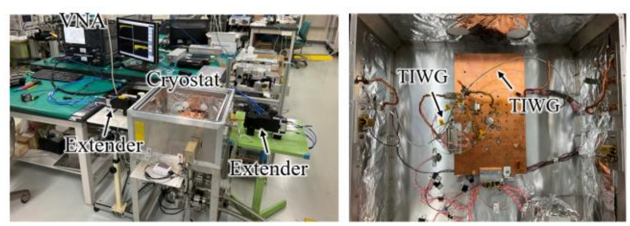
The development of Atacama Large Millimeter/submillimeter Array (ALMA) Band 2 receiver [1] has been led by European Southern Observatory (ESO) in collaboration with several countries under contract/agreement. The radio frequency (RF) range covers 67–116 GHz band, which is challenging development for RF components in terms of wide bandwidth. In this development, National Astronomical Observatory of Japan (NAOJ) has contributed to the development, production, and testing of wideband optical components including the waveguide orthomode transducer (OMT) [2]. The OMT should be very low insertion loss because of the design and its operating temperature. However, it is essential to understand their characteristics at cryogenic temperatures because the losses directly affect the receiver performance. Nevertheless, theoretical conductivity and surface roughness model have been normally applied to estimate component losses without verifications [3]. Recently, measurements of waveguide attenuation constant at cryogenic temperature were reported in [4], which improve the estimation accuracy for insertion loss of waveguide components under cooling. However, this system does not allow to directly measure frequency dependence of *S*-parameters of waveguide components. In this research, aiming to measure the insertion and return losses of ALMA Band 2 OMT at cryogenic temperature, we established a cryogenic measurement system in 67–116 GHz band.

II. Measurement System

We established a cryogenic measurement system as shown in Fig. 1. This system consists of a measurement instrument at room temperature with a vector network analyzer (VNA) and two frequency extenders in 67-116 GHz band, and a cryogenic system with vacuum feedthroughs (FTH) and thermal insulation waveguides (TIWG). Since the insertion loss of the OMT is approximately 0.2–0.3 dB for both polarizations at room temperature, a high-accuracy cryogenic measurement



(a)



(b)

Fig. 1. (a) Schematic diagram of cryogenic measurement system. This system consists of a VNA, extenders, FTHs, and TIWGs. (b) Photographs of the measurement system for (left) overview and (right) inside.

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system should be necessary. To realize high-accuracy measurements, we performed Thru-Reflect-Line (TRL) calibration [5] at the output port of TIWGs, thereby de-embedding the error terms of FTHs and TIWGs from measurement results. However, TRL calibration requires at least three vacuum cooling cycles, thus it is necessary to have repeatability of transmission characteristics in cryogenic systems. In addition, the characteristics of the extenders are not stable in long time, thus TRL calibration cannot be properly performed in this measurement system, which takes 12 hours for one cooling cycle. To avoid above extender's drift, we calibrated at output ports of the extenders before all calibrations and measurements. This calibration method makes it possible to eliminate extender's drift.

III. *S*-PARAMETER MEASUREMENT AT ROOM TEMPERATURE

To verify that our calibration method is worked properly, we compared the results with our method and the results measured by directly connecting the OMT to the extender. The measured insertion losses were shown in Fig. 2. In these results, we have de-embedded the error terms of FTHs and TIWGs and compensated the insertion loss of the waveguide transition that is necessary for the OMT measurements from the measured results. For the magnitude of S_{11}, these results are compatible at the higher frequency. However, at lower frequency, there are large differences between our method and direct measurements. We suspect that the assumption, the $|S_{11}|$ is less than $|S_{11} - S_{21} \cdot S_{12}/S_{22}|$, does not work well due to the high insertion and return losses of the error terms at lower frequency and gives rise to the limitation of our calibration method and this measurement system. On the other hands, the magnitude of S_{21} with our method are consistent with that of direct measurements except for the lower frequency. Based on this result, the insertion loss above 80 GHz could be measured with high accuracy.

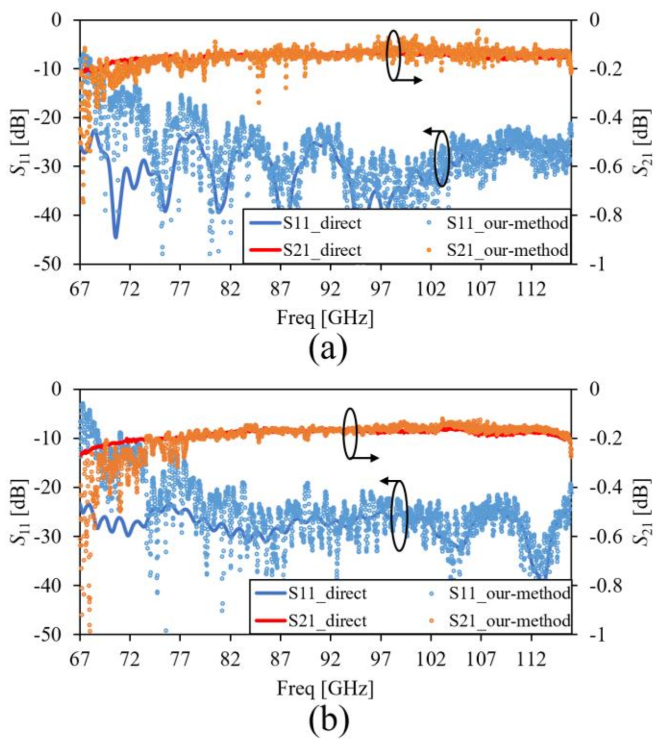

Fig. 2. Measured magnitudes of S_{11} and S_{21} of the OMT (a) for H-pol and (b) V-pol. Solid lines indicate the results that measured by directly connecting the OMT, and open circles indicate those that measured the OMT with our method.

IV. *S*-PARAMETER MEASUREMENT AT CRYOGENIC TEMPERATURE

The insertion and return losses of the ALMA Band 2 OMT were also measured at cryogenic temperature. These results have been included in an extended paper submitted to the IEEE Transactions on Terahertz Science and Technology. This paper notes a practical issue of the OMT that fabricated with split block techniques.

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