Development of a 385-500 GHz Orthomode Transducer (OMT)

Mamoru Kamikura[1,2,3], Masato Naruse[1,2], Shin'ichiro Asayama[2], Naohisa Satou[2], Wenlei Shan[4], and Yutaro Sekimoto[1,2]

[1]Department of Astronomy, School of Science, University of Tokyo, Japan
[2]Advanced Technology Center and ALMA-J project office
National Astronomical Observatory of Japan, National Institutes of Natural Sciences
[3]JSPS Research Fellowship for Young Scientists
[4]Purple Mountain Observatory, Chinese Academy of Sciences
* Contact: kamikura.mamoru@nao.ac.jp, phone +81-424-34 3981

***Abstract*—We report on the development of an orthomode transducer (OMT) for ALMA Band 8 (385-500 GHz). The OMT is a scaled model of that of ALMA Band 4 (125-163 GHz), which has a Bϕifot junction and a double ridge. The transmission loss of the OMT at 4 K was derived to be 0.4-0.5 dB from noise measurements with an SIS mixer. The polarization isolation was measured to be larger than 20 dB from quasioptical measurements. For electromagnetic design, effects of mechanical errors have been studied and then a robust design with allowable mechanical errors of 10 μm has been obtained.**

I. Introduction

An orthomode transducer (OMT) is a passive waveguide device that separates a received signal by a feed horn into its two orthogonal linearly polarized components. For submillimeter receivers, the conventional way to separate orthogonal polarizations is to use a wire grid, which is a quasioptical device that consists of free-standing wires.

Optical systems of a dual polarization receiver with a wire grid or an OMT are shown in Fig.1. The merits and demerits of an OMT compared with a wire grid are the following:

Merits

1) Optical system of a receiver can be quite simple and compact. An ellipsoidal mirror, a corrugated horn, and a wire grid can be removed from that with a wire grid.
2) There is no beam squint between two polarizations.
3) A problem of the life time of a wire grid can be solved.

Demerits

1) A Fabrication is relatively difficult.
2) The Joule loss of the waveguide is added, although an ideal wire grid has almost no loss.

These demerits can be solved if we can design mechanical robust OMT, and if waveguide is gold-plated. The transmission loss at 4 K is calculated as 0.5 dB/ 25 mm at 385 GHz when the OMT is cooled down to 4 K. We assume the conductivity of gold film at 4 K is 1.0 x 10^8 S/m [1].

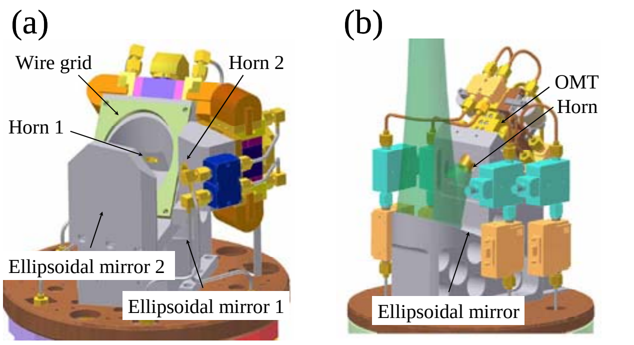

Fig. 1 Optical systems of a dual polarization receiver with (a) a wire grid, (b) an OMT.

Three types of OMTs have been developed for broadband (fractional bandwidth ≥ 26 %) applications at millimeter and submillimeter wavelengths. This classification is similar to that in [2], which is based on the symmetry of the junction.

1) Bϕifot junction with a septum [3-5]
2) Bϕifot junction with a double ridge [6-7]
3) Turnstile junction [8-9]

So far an OMT with a Bϕifot junction and a septum for the 211-320 GHz band [3] was the one demonstrated at the highest frequency range.

We adopted an OMT with a Bϕifot junction with a double ridge. This design has no additional component like septa, and can be realized in a two-split block with conventional CNC milling techniques and partly with electroforming ones. On the other hand, turnstile junction is made in (1) a four-split block with CNC milling techniques, or (2) one block with electroforming techniques. Since Bϕifot junction with a double ridge is simple, it is the most promising for a submillimeter OMT among these designs.

We have developed a 385-500 GHz OMT for ALMA [10]. To meet the ALMA specification, following requirements were set for an ALMA Band 8 (385-500 GHz) [11] OMT from a prototype study of the performance of a receiver [12] with a 2SB mixer [13].

Input Reflection: < - 20 dB
Insertion loss at 4 K: < 0.5 dB
Polarization isolation: > 25 dB

II. Design

A wire-flame model of a 385-500 GHz OMT is shown in Fig. 2. The OMT is basically scaled from that of ALMA Band 4 (125-163 GHz) developed by Asayama *et al.* [7]. The concept of the double ridged OMT is to concentrate the vertical polarization (V-pol.) between two ridges in the center of a square waveguide and to lower the impedance of it. Therefore the polarization can go though the junction. However, the horizontal polarization (H-pol.), which is to a large extent unaffected by the ridges, is divided at the Bϕifot junction because of impedance mismatch at the junction, and then output after recombined at the power combiner.

To optimize dimensions, the OMT was decomposed into five parts as shown in Fig. 3: (1) double ridge, (2) Bϕifot junction, (3) transformer, (4) right angle bend, and (5) side-arm. Each part was optimized with a commercial 3D EM simulator (CST MW Studio). Another commercial simulator (Ansoft HFSS) was also used to cross-check the results. First dimensions of the Bϕifot junction were optimized, then those of the other components were independently optimized based on parameters of the junction.

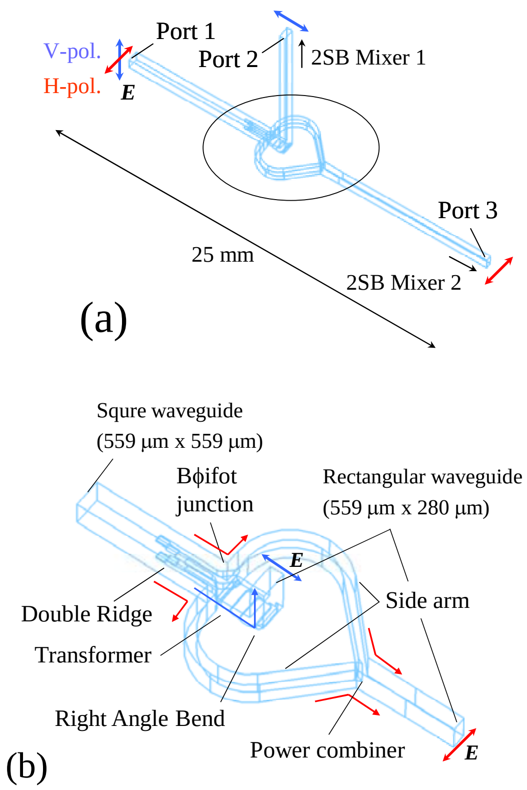

Fig. 2 a) Overview, b) Close-up view of a wire-flame model of a 385-500 GHz OMT.

Mechanical tolerance of waveguide dimensions was investigated in detail, since it becomes crucial in submillimeter-wave range. Fig. 4 shows the mechanical tolerance of the optimized Bϕifot junction. The optimized design is so robust that mechanical errors of 10 μm have little effect on the S-parameters. The double ridge waveguide and the transformer consist of a 3-step Chebyshev transformer, and 2-step one, respectively. The right angle bend is a 2-step type. The numbers of steps are optimized from a point of view of mechanical tolerance. All components of the OMT were confirmed to have mechanical tolerance of 10 μm. The results with two simulators, CST and HFSS, were almost consistent.

Detail dimensions and simulated S-parameters of the whole OMT are shown in Fig. 5. The conductivity of gold films at 4 K is assumed to be 1.0 x 10^8 S/m [2]. For the initial value of the dimensions of the double ridge, the equivalent impedances of each ridge section were calculated based on the theory described in [14] and [15].

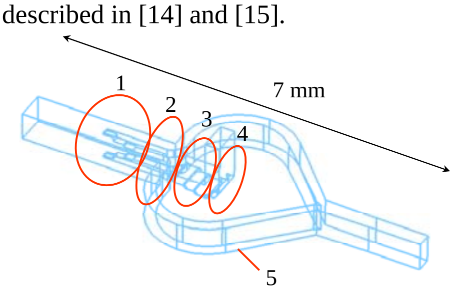

Fig. 3 Decomposed OMT model. (1) Double ridge, (2) Bϕifot junction, (3) transformer, (4) right angle bend, (5) side-arm.

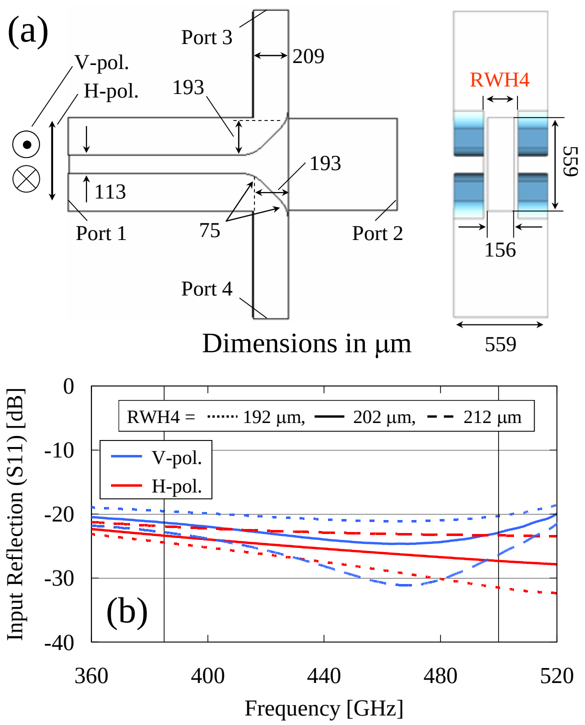

Fig. 4 Mechanical tolerance of the optimized Bϕifot junction (see Fig. 3). a) Dimensions of waveguide, and b) simulated input reflection of the junction with mechanical error of 10 μm at the section named RWH4.

Mechanically, the OMT consists of a two-split block at the center of the E-plane of the horizontal polarization as shown in Fig. 6. It can be made in (a) a three-split block with CNC milling techniques only, or (b) a two-split block with combinations of CNC milling and electroforming techniques. For the section at the vertical branch of the OMT, electroforming fabrication was valid to achieve designed performance. Three-split block scheme looked easier to be fabricated, however, it was not easy to obtain good mechanical contact among three blocks.

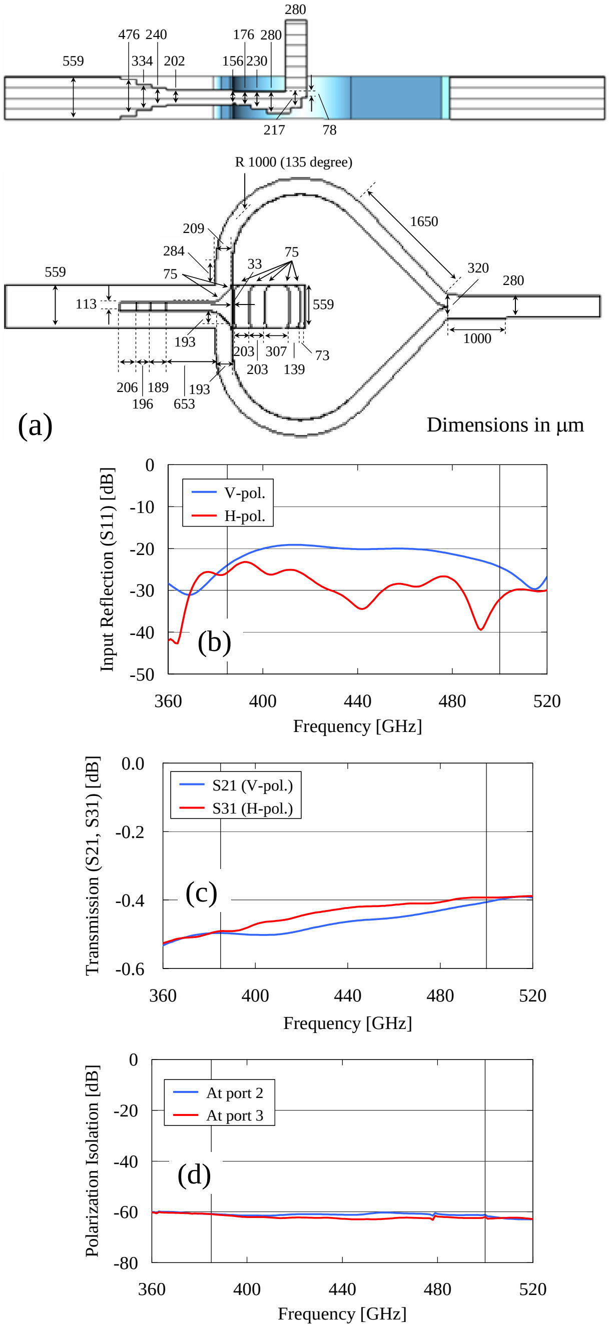

Fig. 5 (a) Dimensions and simulated (b) input reflection, (c) transmission at 4 K, and (d) polarization isolation of the 385-500 GHz OMT. Port definition is shown in Fig. 2 (a).

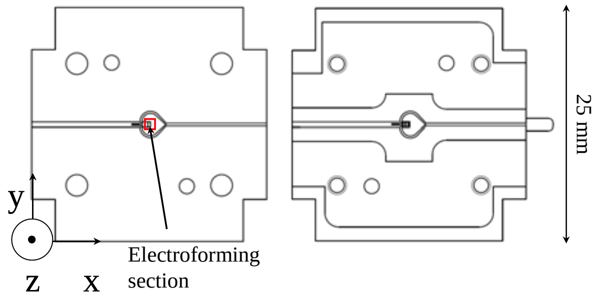

Fig. 6 Mechanical design of the 385-500 GHz OMT. The OMT is a two-split block at the center of the E-plane of the horizontal polarization. For the vertical branch, the electroforming technique was used.

III. Evaluations

The OMT was fabricated by Oshima Prototype Engineering and made of TeCu with gold-plated. Results of the mechanical measurements are shown in Fig. 7. Measurements of xy- and xz-plane are done with a digital microscope, with a non-contact coordinate measuring machine (NH-3SP, Mitaka Kohki Co.,Ltd.), respectively. Dimensions are calibrated with a high precision scale (HL-250, Mitsutoyo Corporation). Typical mechanical error was ~ 5 μm from the measurements.

The polarization isolation of the OMT was measured with a quasioptical method [16]. We measured beam patterns of a corrugated horn [17] with and without an OMT as shown in Fig. 8. The increase in the amplitude of the cross-polarization due to the OMT at the center (0 degree) represents the

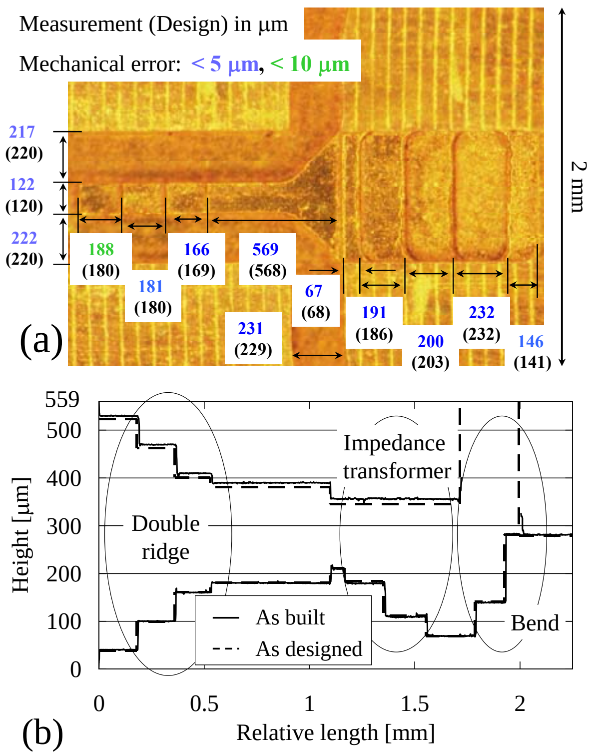

Fig. 7 Mechanical measurements over the area around the Bϕifot junction at a) xy-plane, b) xz-plane. Coordinate system is defined as in Fig. 6.

polarization isolation of the OMT. Polarization isolation of the OMT was measured to be larger than 20 dB over the 385-500 GHz band.

Fig. 9 shows the measured and simulated transmission loss at 300 K of the OMT. The measurements were done with a submillimeter VNA shown in Fig. 10. The conductivity of gold at 300 K is assumed to be 1.1 x 10^7 S/m [18], which is derived from a curve-fitted formula when ~ 1 μm of surface roughness is taken into account.

The additional noise due to the loss of the OMT was measured with an SIS mixer [19] as shown in Fig. 11. We measured the DSB noise temperature of an SIS mixer with and without an OMT. From these measurements, transmission loss of the OMT at 4 K was derived to be as low as 0.4-0.5 dB as shown in Table I. It is reasonably expected from the waveguide length of 25 mm and is consistent with simulated transmission loss in Fig. 5.

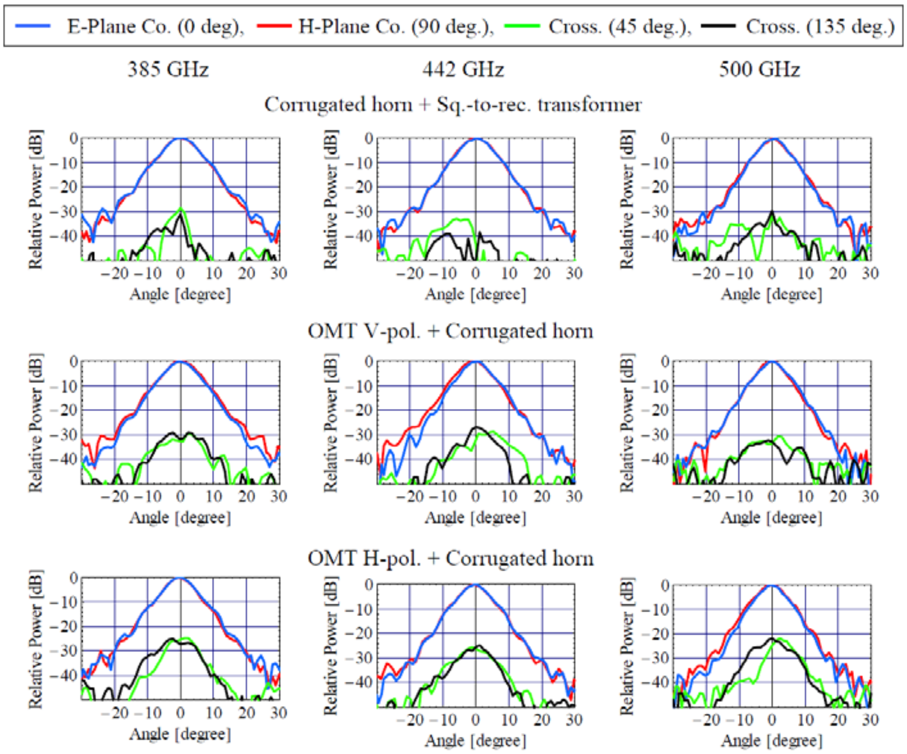

Fig. 8 Measured polarization isolation [16] of the OMT. These panels show beam patterns of the co- and cross- polarization of a corrugated horn [17] and the OMT. The upper, the middle, the lower panels show those of (1) the corrugated horn and a square-to-rectangular transformer, (2) the vertical branch of the OMT and the corrugated horn, (3) the horizontal branch of the OMT and the corrugated horn, respectively.

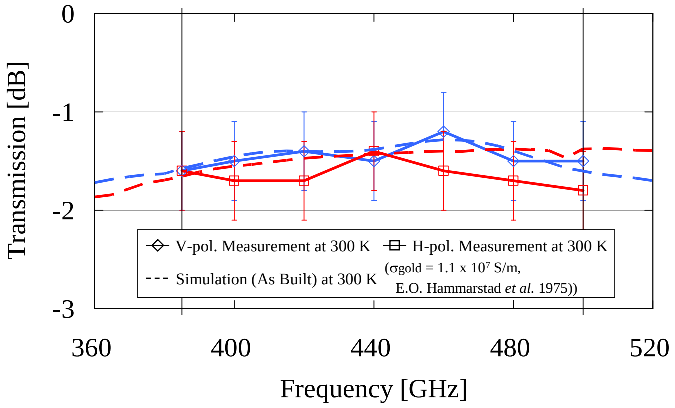

Fig. 9 Measured transmission loss and as built simulation of the OMT and a square-to-rectangular transformer (transmission is ~ 0.1 dB) at 300 K. The error bars are derived from reproducibility.

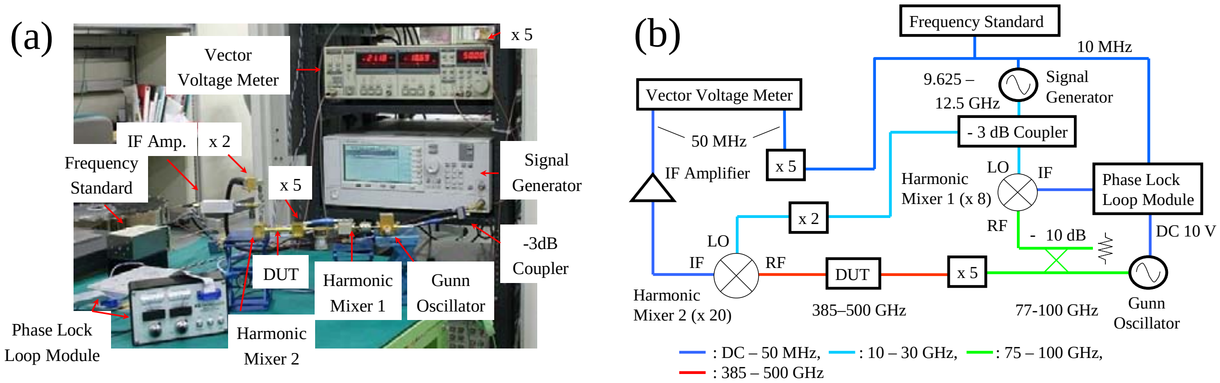

Fig. 10 (a) Photo and (b) block diagram of a 385-500 GHz vector network analyzer.

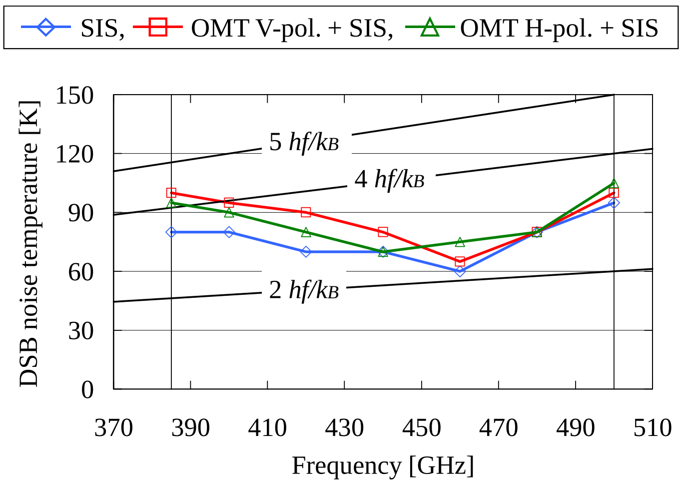

Fig. 11 The DSB noise temperature of an SIS mixer with and without the OMT. The noise increase was ~ 5-10 K around the band edges, and less than typical error of ~ 5 K at the band center.

TABLE I.

MEASURED CONTRIBUTIONS OF EACH COMPONENT TO THE RECEIVER NOISE.

Component	385 GHz				440 GHz				500 GHz			
	Gain [dB]		Te [K]		Gain [dB]		Te [K]		Gain [dB]		Te [K]	
	DSB	OMT + DSB	DSB	OMT + DSB	DSB	OMT + DSB	DSB	OMT + DSB	DSB	OMT + DSB	DSB	OMT + DSB
Window, Filter	-0.7		33	33	-0.5		25	25	-0.6		30	30
OMT	0	-0.5	0.0	0.6	0	-0.4	0.0	0.4	0	-0.4	0.0	0.4
LO coupler	-0.5		0.6	0.6	-0.4		0.4	0.5	-0.5		0.6	0.6
DSB mixer	-0.8		31	35	0.0		29	32	-2.6		35	39
Cooled IF chain	25		23	28	25		18	21	25		35	41
Warm IF chain	30		0.6	0.6	30		0.4	0.4	30		0.9	1.0
Sum	--	--	88	98	--	--	74	79	--	--	102	112

IV. CONCLUSIONS

We have developed a 385-500 GHz OMT for ALMA Band 8. The OMT is based on a Bϕifot junction with a double ridge. Mechanical tolerance of the waveguide structures was studied in detail. The transmission loss at 4 K was derived to be as low as 0.4-0.5 dB with an SIS mixer. The polarization isolation was measured to be larger than 25 dB over the 385-500 GHz band with a quasioptical method.

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