# Recent research on (sub)mm-wave OMTs at NAOJ

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***Abstract*—Dual-ridged waveguide orthomode transducers (OMTs) are a well-proven type of high-performance waveguide components used for the separation of orthogonal linear polarizations, and wideband designs have been recently demonstrated at frequencies as high as 500 GHz. In this paper, we review recent work at NAOJ on this type of OMTs and investigate the limits of performance in a narrower bandwidth.**

***Keywords*— Orthomode transducers, millimeter-wave circuits, polarization splitter, fabrication techniques, radio astronomy.**

## I. INTRODUCTION

Orthomode transducers (OMTs) are key waveguide components to separate orthogonal linear polarizations. They are thus very important in applications which require polarization discrimination such as radio astronomy or communications. In radio astronomy, polarization is useful to extract additional scientific information, whereas in communications, it is used to reutilize the available spectrum. OMTs receive two linear orthogonal polarization signals, vertical (V) and horizontal (H) for convenience, within the same frequency band coming from a common square or circular waveguide, and separate them into two separate rectangular waveguides.

Several of the waveguide OMT architectures common at microwave frequencies have been applied to frequencies as high as 300 GHz [1-7], but the number of OMTs at sub-millimeter wavelengths is still limited [8-9], mainly due to fabrication challenges. Among existing OMT types at mm and sub-mm wavelengths, dual-ridged OMTs represent a good balance between performance and ease of fabrication. They can achieve good impedance matching in all ports, good polarization discrimination and isolation between output ports, and low insertion loss, at the same time they can be fabricated in two split blocks by direct machining in combination with wire electro-discharged machining (EDM). At the National Astronomical Observatory of Japan, we developed this type of OMTs towards the production of 73 OMTs for the 125-163 GHz [5] and 385-500 GHz [8] heterodyne receivers for the ALMA (Atacama Large Millimeter/sub-millimeter Array) telescope. In recent years, we have successfully designed and fabricated wideband components covering the 67-116 GHz [10] and 275-500 GHz [11] frequency ranges. In this contribution, we summarize the results in [10] and [11], and apply our know-how to maximize performance of dual-ridged waveguide OMTs at a narrower bandwidth considering practical aspects related to electromagnetic design. In particular, we have designed an OMT with the highest possible performance in the 195-290 GHz band. The chosen bandwidth corresponds to an extended version of the ALMA band 6 (211-275 GHz).

## II. PREVIOUS DESIGNS AND EM SIMULATIONS

We have recently developed state-of-the-art wideband OMTs at mm and sub-mm wavelengths [10]-[11] using the dual-ridged waveguide topology shown in Fig. 1. Successful designs have been achieved thanks to the use of modern electromagnetic (EM) software, which allows high parametrization of the design through a model, the combination of different EM analysis methods, and advanced optimization algorithms. In those previous designs, the goal was to design OMTs as broadband as possible (55-60% fractional bandwidth) with the highest possible performance. In this contribution, we target a more moderate but still wide bandwidth, 195-290 GHz (~40% fractional bandwidth), and investigate the limits of performance we can achieve based on our previous models. This OMT was firstly designed using a hybrid Mode-Matching (MM) + Finite Elements (FE) method in the commercial software WaspNET. Then, the same design was evaluated with Finite Elements Boundary Integral (FEBI) in WaspNET and with the FE software HFSS.

The comparison of the results of return loss using the three EM simulation methods showed good agreement for the H polarization, in spite of some degradation of performance to a level around 25 dB, and some discrepancies for the V polarization, for which the two FE methods showed performance between 20 and 25 dB. These results are shown in Fig. 2. In order to understand the discrepancy in the V polarization better, two adjacent FE elements in our model were combined into a single FE element, as shown in Fig. 3, which yielded results closer to FEBI and HFSS. This result highlights the importance to carefully choose the appropriate simulation method for each part of the hybrid model when trying to push the limits of performance. The new MM+FE model produced results consistent with FEBI and HFSS in subsequent designs.

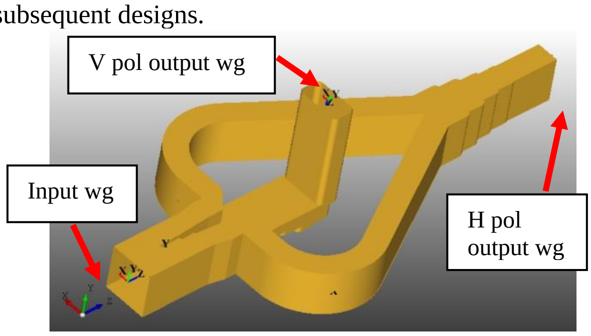
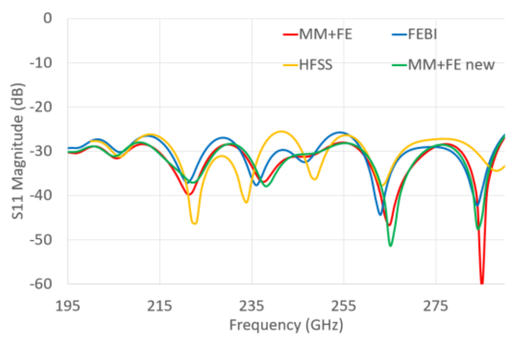



Fig. 1. 3D schematic of the simulation model of a dual-ridged waveguide (wg) OMT. This design targets the 195-290 GHz bandwidth.

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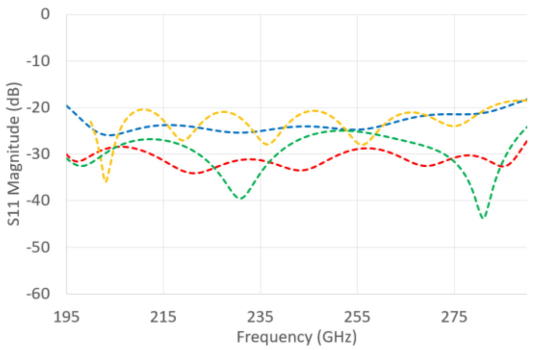


Fig. 2. Return loss simulation results (as S11) for the designed OMT using MM+FE, FEBI and HFSS methods. The top figure corresponds to the H polarization, whereas the bottom figure shows the results for the V polarization. HFSS results for the V polarization include ripples due to impedance mismatch between the rounded-corner output waveguide and the rectangular output port. Results for the improved MM+FE model in Fig. 3 are shown in green color.

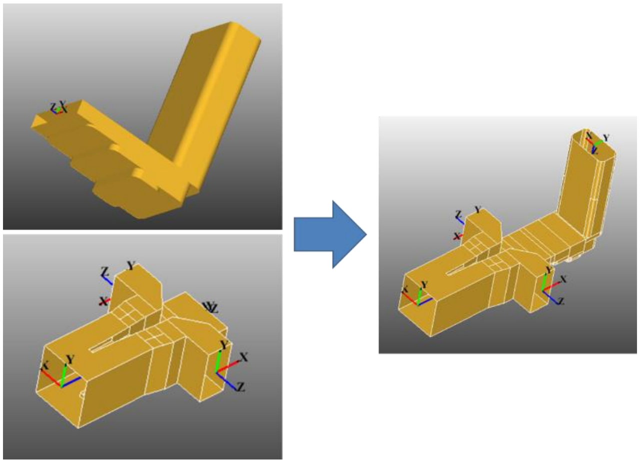

Fig. 3. Combination of OMT junction with E-plane bend of vertical polarization output into a single FE element.

## III. Results

Two prototypes of the designed OMT for the 195-290 GHz band were fabricated and tested. In order to speed up testing, the prototype units were measured with standard WR-4.3 (864 µm x 432 µm) waveguide extenders and without transitions to the 940 µm x 470 µm output waveguides. A square to WR-4.3 waveguide transition which could be rotated 90 degrees was used for the common input waveguide. Results are shown in Fig. 4. Reflection loss is better than 20 dB with all degradations introduced by the measurement setup uncompensated, cross-polarization is better than -30 dB and isolation is better than 40 dB. The measurement results for both prototype units were similar.

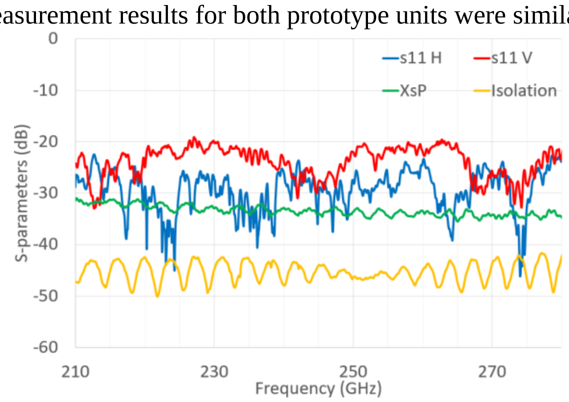


Fig. 4. Measurement results of prototype OMT unit without using output transitions and without compensating for the effect of the rectangular-to-square input transition.

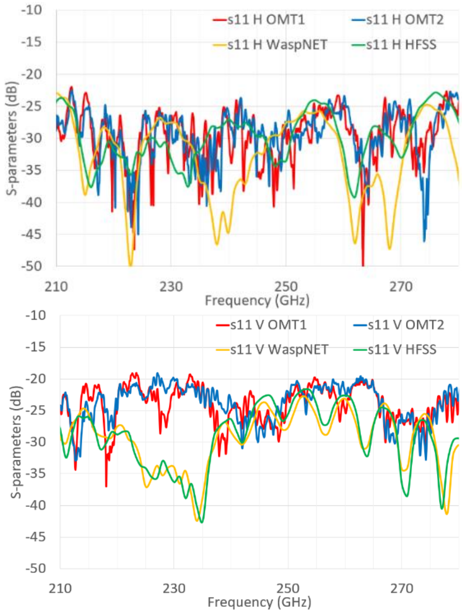


Fig. 5. Comparison of measurement results for two prototype OMT units and WaspNET and HFSS simulations including all transitions and steps in the actual measurement. (Top) H polarization, (Bottom) V polarization

Measurement results were compared with simulations modeling the measurement setup. Results showed that H polarization measurements were similar to simulations, which hints the actual performance of the OMT in terms of insertion loss is in the order of 28 dB. Results in V polarization were not bad but different from simulations. This was tracked down to fabrication errors.

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