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Wideband OMT with Modified Bøifot Layout and Co-aligned Waveguide Outputs

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***Abstract*—We present the design of an orthomode transducer, OMT, that aims for the frequency band 210 - 375 GHz. The OMT employs a modified Bøifot layout. The OMT is optimized to fit into the tight spatial constraints, e.g., of the ALMA cartridge and harmonizes the receiver cartridge components for both polarizations by allowing use of the same configuration and components in both polarization chains. The OMT features a built-in novel broadband 90-degree waveguide twist, which minimizes the insertion loss by removing the H-split waveguide while eases receiver components integration with the 2SB mixers in the ALMA cartridge. The OMT was designed and optimized using HFSS™ 3D simulation software and tested with Keysight PNA-X VNA and three VNA extensions WR5.1, WR3.4 and WR2.2 in order to cover ultra-broad RF band.**

***Index Terms*—Orthomode transducer, waveguides, ALMA receiver cartridge, dual-polarization receivers**

I. INTRODUCTION

An orthomode transducer, OMT, is a polarization diplexer that allows to physically separate the polarization components of an incoming signal. A typical place for such diplexer is between the feed, e.g., a corrugated horn, and the first stage of a dual-polarization receiver, e.g., a mixer. Consequently, the input port of an OMT should allow propagation of both orthogonal linear polarizations and the OMT RF insertion loss directly affects the receiver noise performance. A few derivatives of the Bøifot OMT layout [1] are currently used in the ALMA Band 3, 4, 5, 6, 8 receiver channels [2] providing the superior beam squint (Fig.1) at the sky with the single feed for both polarizations as compared to the receivers using polarization grids and thus employing individual feeds for each polarization, requiring careful mechanical alignment. The implementation of an OMT in the next generation of ALMA receivers, e.g., ALMA Band 7 is therefore a desirable option.

The ALMA receiver cartridges provide a very confined space for placing the different receiver components particularly considering all cold optics with bigger mirrors, especially for lower frequency bands with all-cold optics, e.g., ALMA Band 5 [3] and even Band 6.

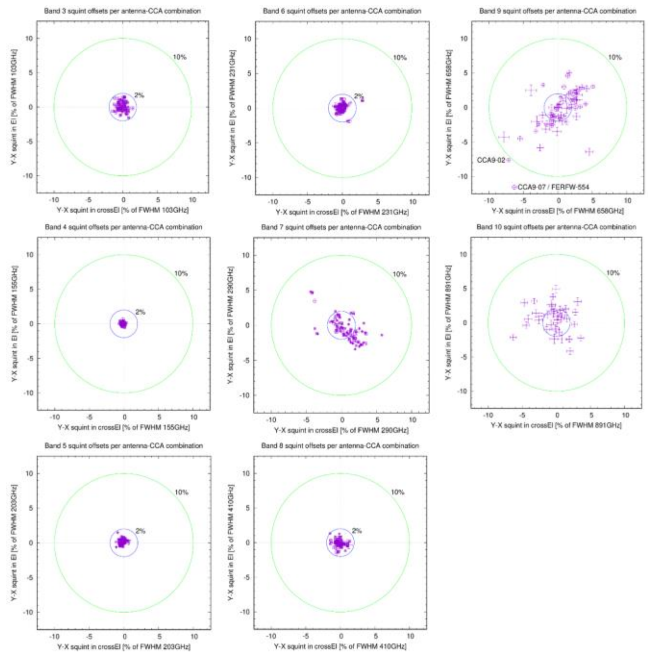

Fig. 1. On-sky Y-X polarization beam squint in cross-elevation vs. elevation coordinates in units of the beam FWHM at the observing frequency for ALMA Bands 3 to 10. Multiple measurements have been averaged per antenna-CCA combination when possible. The 10% specification limit is shown (green circle), in addition to a threshold of 2% which all existing single-horn receivers (Bands 3, 4, 5, 6, 8) could comply with and which may be a practical future goal. This figure corresponds to Figure 8 in [4].

The original Bøifot OMT's T-layout precludes using the same components and arrangement of the receivers for both polarizations, which would be a disadvantage for, e.g., ALMA receiver cartridge production. However, this difficulty could be circumvented by employing slightly more complex OMT configurations, which include additional split of the block and 90-degree H-plane turns of the waveguides at the Y-junction branch as in ALMA Band 5 OMT [5]. Though, this solution has a drawback of featuring an extended H-split waveguide for one polarization that may result in a RF leak and correspondingly an increased insertion RF loss. This is especially true for an OMT at higher frequencies, e.g., 210 - 375 GHz where the

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waveguide dimensions are substantially smaller and an OMT requires even higher accuracy for fabrication.

In order to avoid the unwanted H-split and risk of increasing the insertion RF loss, we propose in this paper the introduction of an integrated 90-degree wideband waveguide twist placed close to the OMT polarization splitting junction, PSJ. This allows to align OMT output waveguides and avoid using external 90 - degree twist as in [5, 6]. By harmonizing the OMT outputs, we open a possibility of using the same receiver layout and components for both polarizations.

II. OMT Layout & Simulations

The OMT design largely follows the one successfully used in the ALMA Band 5 receiver. However, in order to achieve substantially broader fractional bandwidth, 210-375 GHz or 57,6% of the center frequency and better control the internal matching, additional elements were added to the polarization splitting junction: a multi-step transformer was added to the direct output of the PSJ and in multiple circular recesses to Y-junction branch of the PSJ. Fig. 2 demonstrates the HFSS 3D model of the proposed OMT. The orange arrow points to the waveguide 90-degree 3-section twist.

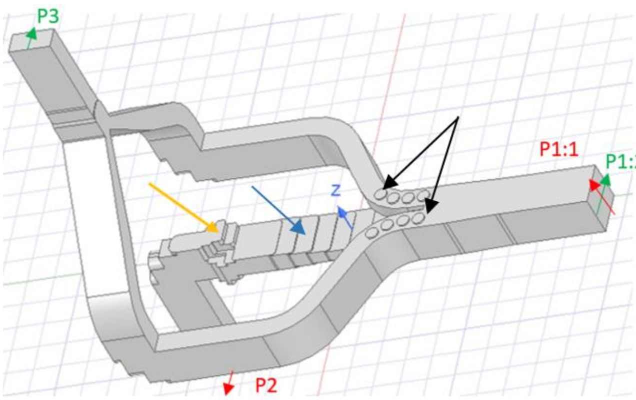


Fig. 2. HFSS optimized OMT 3D model. Yellow arrow points on the built-in twist. Polarization split illustrated by color-coded port denotations. The multi-step transformer in the direct branch of the PSJ marked by blue arrow. The multiple circular recesses in the Y-junction branch of the OMT PSJ marked by black double-arrow. The OMT to be fabricated off three parts with split going in the middle of the square input waveguide, dimensions 760x760 µm, in the direction of P1:2 vector; these two parts formed PSJ and the second split goes in the middle of the output waveguides, dimensions 380x760 µm, in the plane of vectors P3 & P2.

In order to keep the length of the waveguides inside OMT to possible minimum and thus introduce minimum insertion RF loss, we would need a compact 90-degree waveguide twist for integration inside the OMT, e.g., such as described in [7, 8, 9, 10]. The twist should also be compatible with split-block fabrication technique intended to fabricate the OMT. Another obvious requirement is that the twist should provide 56% of the fractional RF band and deliver 210 - 375 GHz operational bandwidth.

The required bandwidth could be provided by the twist suggested in [8], however its design is hardly suitable for the split-block fabrication. The twists suggested in [9, 10] could be accommodated to fabrication using split-block technique but do not provide the required RF bandwidth. Following these conclusions, we employ the twist suggested [9] in a multi-step design in order to extend the RF band. Fig. 2 illustrates the initial design of the 3-stage twist with the twist [9] in the central position while the two adjacent peripheral steps use the twist shape similar to presented in [11].

During design phase, all major waveguide components of the OMT, the polarization splitting junction, the Y-junction, the twist and H-turns were HFSS simulated and optimized separately with the goal of having input/output reflection loss well below -20 dB. Thereafter, the complete HFSS OMT model was assembled by combining these partial models and the optimization procedure was run for the complete OMT also applying realistic constraints of the fabrication using precision CNC miller. The results of the HFSS simulations are presented in Fig. 3.

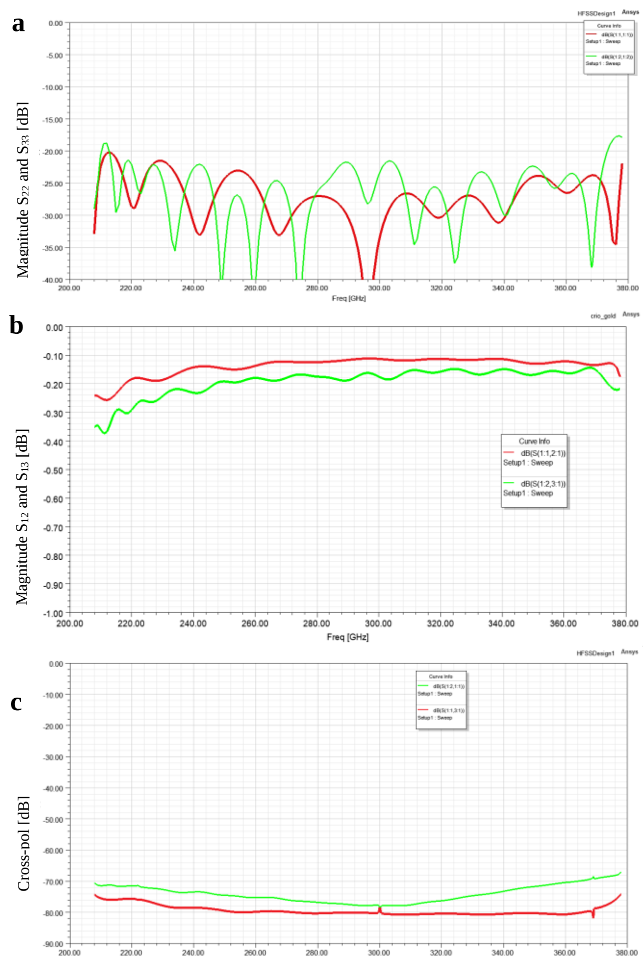


Fig. 3. HFSS simulation results of the OMT. *Fig. 3a* displays the return loss at the square waveguide input. *Fig. 3b* presents the insertion RF loss for each polarization (for electroplated gold assigned as material for the OMT in HFSS). *Fig. 3c* presents the cross-pol simulation results.

III. OMT Fabrication & Characterization

The OMT was manufactured in-house in tellurium copper using a precision CNC milling machine from Kern GmbH. Subsequently, the produced parts were electroplated with 0.5 µm of Gold. Fig. 4 shows the manufactured OMT.

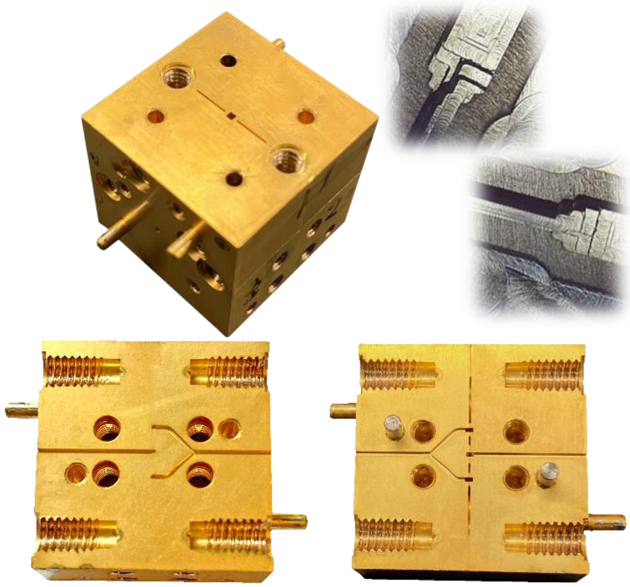
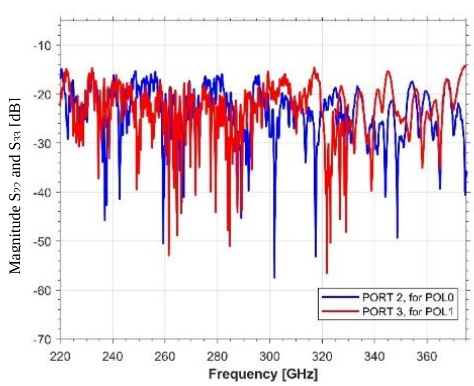


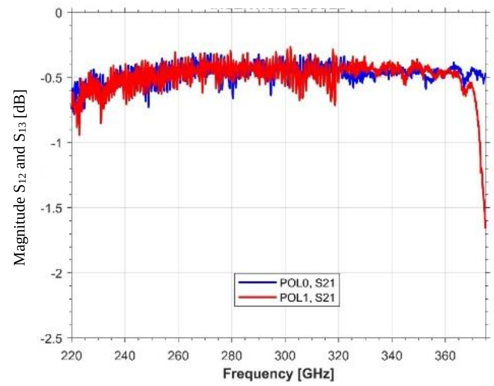
Fig. 4. Manufactured OMT. Pictures show assembled OMT with the square input waveguide, top photo. Solid part of the second split (left) and the split part that containing the PSJ, right. In this split all waveguides are divided in the middle of the broad wall (non-radiating split) and are co-aligned. The OMT is manufactured from Tellurium copper and gold-plated. The inserts show the details of the 90-degree split.

The OMT was characterized using Keysight PNA VNA and frequency extension modules WR5.1, WR3.4 and WR2.2. Because the OMT uses custom-sizes of the waveguide 380 x 760 µm and 760 x 760 µm, the measurements required adapters for rectangular waveguides and transitions rectangular-to-square from the waveguides of the VNA frequency extension modules. The contribution of the transitions used for the measurements are later de-embedded using back to back direct measurements of the transitions themselves., yielding the OMT's characterization results, depicted in Fig. 5 below.

a



b



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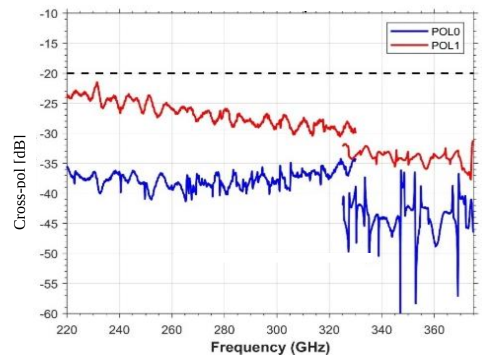

Fig. 5. Measured performance of the OMT. *Fig. 5a* displays the return loss at the square waveguide input. *Fig. 5b* presents the insertion RF loss for each polarization. *Fig. 5c* presents the cross-pol measurement results.

IV. Conclusion

We present the design and characterization of the modified Bøifot orthomode transducer that covers the frequency band 210 - 375 GHz, i.e., covering a 56% fractional bandwidth. The OMT design features built-in novel 90-degree waveguide twist that allows to minimize length of the H-split waveguides and thus minimizes a risk of RF leaks and extra insertion losses. Additionally, the twist allows placing the OMT outputs co-aligned that facilitates the following receiver components design and helps fitting into a tight space, e.g., of the ALMA receiver cartridge the receiver cartridge. The manufactured prototype performance follows well the simulations in HFSS. An early version of the OMT with an external twist was used in SEPIA345 [6] receiver that is installed at APEX telescope in Chile [13] since January 2020.

Acknowledgments

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