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A Dual Ridge Broadband Orthomode Transducer for the 7-mm Band

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Abstract In this work we present a Q-band waveguide orthomode transducer (OMT) based on a dual ridge structure. It was designed to be used in astronomical projects were an excellent broad-band performance is mandatory. Of particular interest is the case of ALMA Band 1 (originally set at 31-45 GHz) project which will need several OMTs with outstanding performance and demonstrated manufacturability. By using a symmetrical structure, low cross-polar level and good input matching are achieved over a broad bandwidth (37 %). The proposed design incorporates an octagonal mode converter which allows the unit to be directly mated with the horn avoiding cross-polar issues at the interface. The OMT was designed to have a compact configuration and easiness of fabrication, both crucial features in projects where several units (up to 70) have to be constructed.

Keywords Orthomode transducer · Waveguide components · Dual ridge structure · Q-band components

1 Introduction

The Atacama Large Millimeter Array (ALMA) is the largest array of radio-astronomical antennas ever devised. Each antenna will cover the spectroscopic window from 30 to 950 GHz with ten different receivers. The lowest-frequency band (so-called Band 1), which will cover the 7-mm range, was not implemented during the first construction phase of the telescope, but will be included during a second upgrading phase. Band 1 will allow the study of several important radio-astronomical phenomena, like molecular gas in high red-shift galaxies, high resolution CMB, dust in proto-planetary disks, and conventional observations of southern hemisphere targets [1].

The specifications set by ALMA for its receivers are stringent. All the receivers should work on a dual-polarization configuration with a cross-polar isolation lower than −25 dB. Moreover, the frequency coverage of every band is rather large. In the particular case of

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Band 1 the proposed frequency range is 31 to 45 GHz, giving a fractional bandwidth of 37 %. Given these specifications we have selected as polarization splitter a waveguide orthomode transducer (OMT). For an adequate interface of the OMT with other Band-1 receiver components we have set some additional specifications. We aimed to obtain reflection losses below −20 dB and isolation between the two polarization channels better than −50 dB.

There are several designs for an OMT. The most common ones for broadband operation are the Boiffot [2], the turnstile [3, 4] and the dual ridge OMTs [5]. The main advantage of the latter over other designs is its simple fabrication process using conventional CNC milling machines, without the need of high-precision alignments, or the need for high precision pins and septum. Specifically, we have decided to implement a double ridged structure, similar to the design for Bands 4 and 8 of ALMA [6, 7]. We improved the original design by, first, incorporating a built-in compact circular to square waveguide adapter at the input port and by, second, redesigning and optimizing the complete structure with special emphasis on the dual ridge structure which dominates the cross-polar level and reflection losses of the device. We have found that a critical dimension to improve the cross-polar level was the distance between the dual ridge and the octagonal mode converter. The radius of curvature of the two arms was also optimized in order to get best results in the lower part of the band. In this way we have achieved the desired broad-band performance and diminished the previously published cross-polar levels [6].

2 OMT Design

Figure 1 shows the overall layout of the designed dual ridge OMT. The input port of the device is an octagonal mode converter, which converts the input from a circular to a square waveguide supporting the two orthogonal polarization modes. These orthogonal modes are separated in the dual ridge structure, which is the core component of the device. One polarization mode is bent by an E-Bend structure, while the other is recombined by the Y-Junction. Finally the outputs of the OMT are two standard WR-22 waveguide ports, named

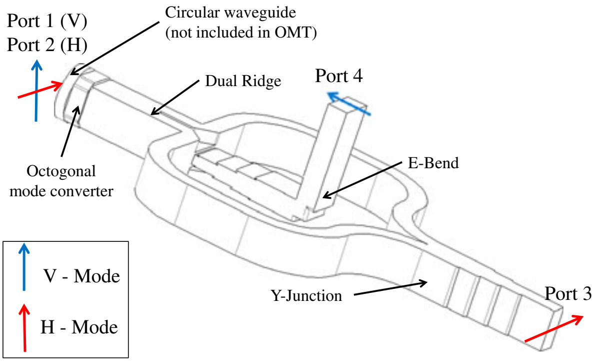


Fig. 1 Model of the dual ridge OMT. The input port is the octagonal converter which allows the OMT to be directly connected to the circular waveguide coming from the horn. The circular waveguide supports two orthogonal modes (H and V). These modes are converted in square waveguide modes and then separated by the dual ridge structure. H modes are recombined by a Y junction and output at port 3. Mode V continues in the same direction and output through port 4.

ports 3 and 4, respectively, one for each orthogonal polarization. In the following section the design and performance of each part is reviewed.

2.1 Octagonal Mode Converter

To facilitate the assembly of the receiver, where the device will be used, the OMT was designed to be directly connected to a conical corrugated horn with circular waveguide input (Fig. 2). A solution for the Band 1 horn was previous published in [8]. In order to avoid excitation of higher order modes, which will cause an increment in the cross-polarization value, it is important to assure that the transition keeps the symmetry of the structure. We decided to use an octagonal mode converter, designed to be mated to a circular waveguide with a radius of 3.81 mm. This dimension allows the two orthogonal TE11 fundamental modes (labeled as H and V modes in Fig. 1) to propagate between 30 and 50 GHz. The TE11 modes present in the circular waveguide are converted, by the octagonal mode converter, into orthogonal TE10 and TE01 modes propagating in the inner square waveguide. The design of the mode converter follows reference [9] and the ALMA Band-5 solution for the OMT-to-horn transition [10]. The advantage of using octagonal transitions is that it increases the size of the OMT by only few millimeters, without paying any cost in terms of performance when comparing to traditional square to circular converters [11]. To assure the correct alignment of the mode converter with the rest of the OMT, it was built in the same block, avoiding alignment issues during the assembly of the device.

2.2 Dual Ridge

The two orthogonal TE modes present in the square waveguide are separated by the dual ridge structure, depicted in Fig. 3. The purpose of this structure is to concentrate the V mode into the narrow space between the two ridges and the H mode into the two waveguides structures separated by the central ridge. The V mode continues straight into a reduced height rectangular waveguide, which is in cut-off mode for the H mode. Meanwhile, the H mode waveguides are bent and output through two lateral ports with a180 degree difference

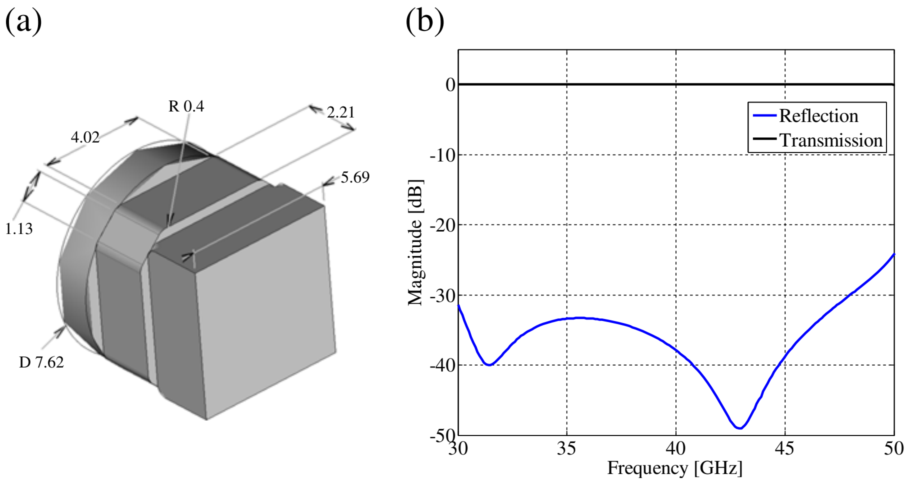


Fig. 2 (**a**) Structure and (**b**) simulated results of the octagonal mode converter.

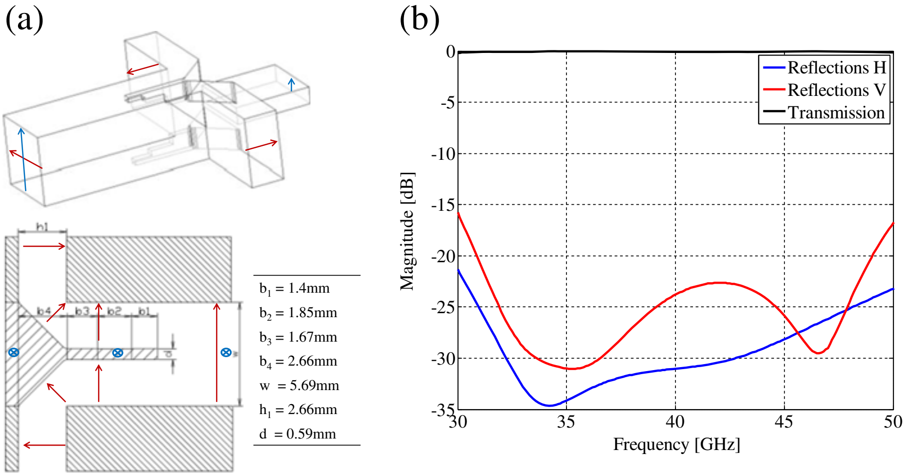


Fig. 3 Dual ridge structure. (**a**) Isometric and top view of the dual ridge structure showing how the H mode (*red arrows*) is bent into two symmetrical outputs while the V mode (*blue arrows*) continues straight to the single output. (**b**) Simulated results for the dual ridge structure.

of phase. The symmetry of the complete structure is fundamental as it prevents higher order modes, specially the TE11, to appear in the square waveguide causing cross-polar talk.

One of the advantages of the dual-ridge structure is its inherent broad-band behavior, allowing the OMT to achieve the specified bandwidth. This structure is the core component of the OMT and the most critical part for broad-band operation. It was careful designed and optimized to reduce the return losses from this structure below – 25 dB all over the frequency range. We have decided to use three steps for the dual ridge as it proves to be enough to cover the specified bandwidth. The final dimensions of the proposed structure are listed in Fig. 2 which also shows the simulated reflection losses of the structure.

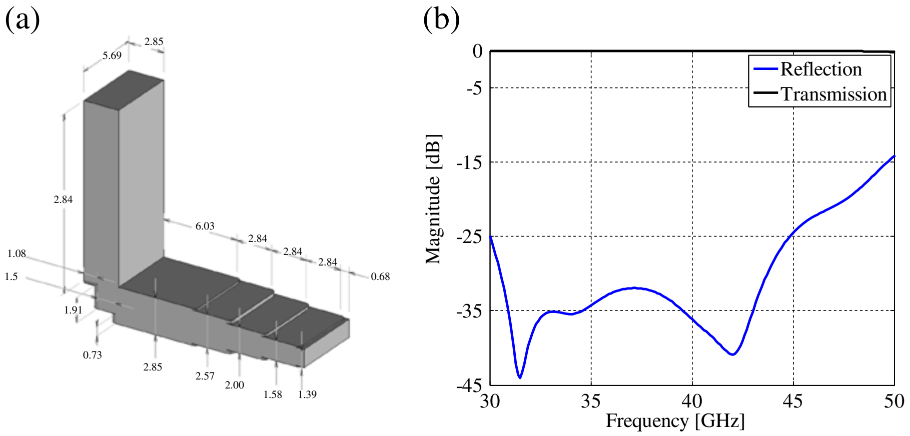


Fig. 4 The E-Bend drives the H signal to the output located in the top part of the OMT. (**a**) 3-D view of the E-bend. (**b**) Return losses and transmission of the structure.

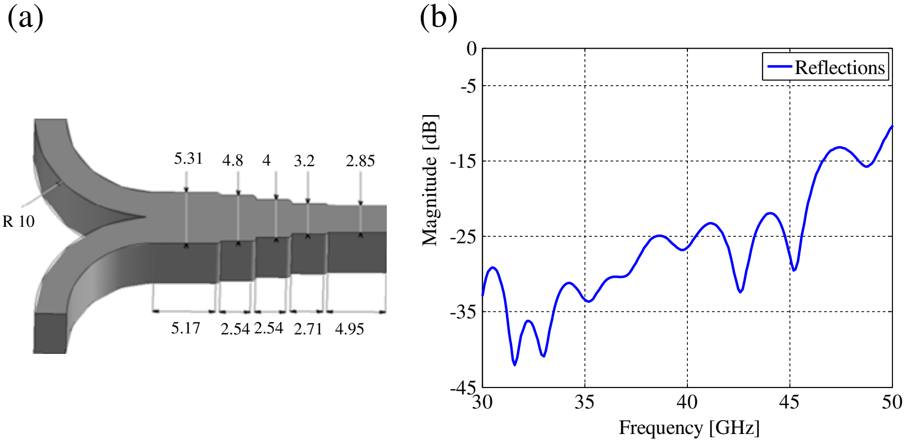


Fig. 5 The Y junction has to recombine the two H signal coming from the dual ridge. (**a**) 3D view and its most important dimensions. (**b**)Simulated return losses of the structure.

2.3 E-Bend and Y- Junction

After the dual ridge the V-mode is bent by an E-bend structure and output through port 4. The design and simulated results of this structure are presented on Fig. 4. The reflection losses introduced by this structure are negligible, being below -30 dB all over the band of interest. Meanwhile, the two H-modes signals have to be recombined in a Y-junction whose dimensions and simulated results are presented in Fig. 5. Both structures, the E-bend and the Y-junction, were designed following [12] and were optimized to cover the specified frequency range.

Each one of the parts (circular to square transition, dual ridge guide, E-bend and Y-junction) were designed and optimized separately in a 3D electromagnetic simulator (High Frequency Structure Simulator from ANSYS). Afterwards, a second iteration was necessary to optimize the performance of the OMT working as a whole. Special emphasis was exercised during this final optimization process to avoid resonant behaviors in the cross-polar and isolation features. The final simulation results, presented in the following section, account for the losses on the waveguide walls and for the machining effects, as the fillets in the corners and the surface roughness.

Fig. 6 The OMT was build using split-block technique. At the left side an assembled OMT is shown, were the input octagonal port can be observed. At the right side the three blocks that compose the OMT are shown. The overall block dimensions are 72×30×50 mm^3.

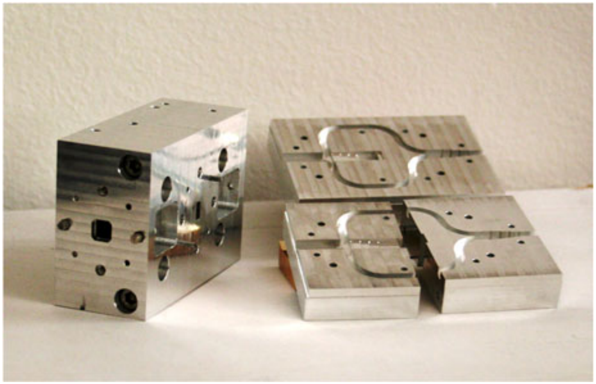
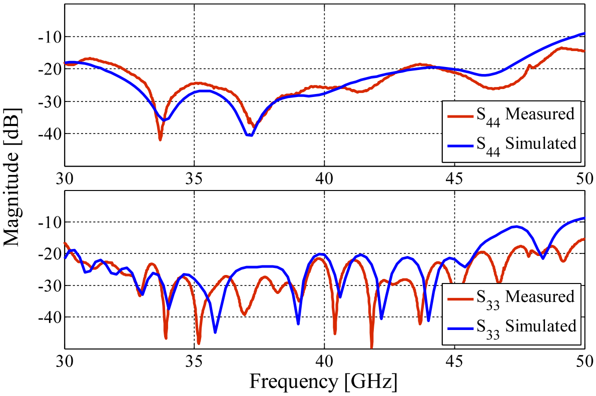


Fig. 7 Measured and simulated reflection losses for the dual ridge OMT. The agreement between them is excellent. Reflection losses are below −20 dB all over the band of design (31-45 GHz).

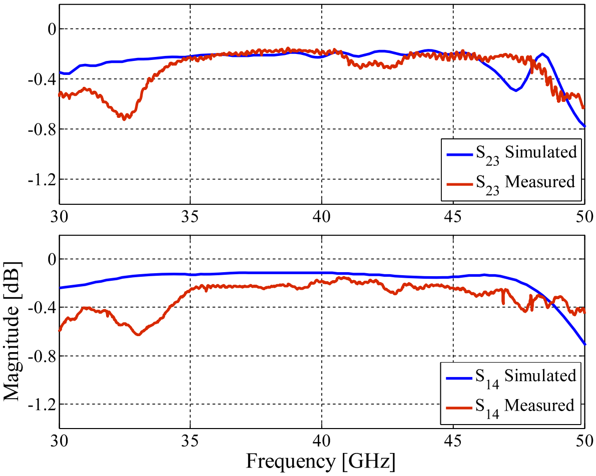


3 Construction and Measurements

The OMT was built using a high precision CNC milling machine. We have used Aluminum 2017 to produce the units as it is inexpensive, light, resistant to corrosion, and has excellent electrical conductivity. The OMT was constructed in three blocks that are tightened by screws and aligned using stainless-steel alignment pins. The octagonal mode converter is built in the same block, avoiding further alignment issues. The fabricated OMT and its three constitutive parts are shown in Fig. 6. We have fabricated three units of the OMT with only few mechanical differences between them. The repeatability was excellent for all the units proving that the fabrication process of this OMT is not only easier than other reported devices but is also reproducible.

The devices were characterized using a Vector Network Analyzer model E8364C from Agilent. A circular load was designed and built to terminate the input port while measuring the reflection losses at ports 3 and 4. Transmission and cross-polar levels were measured using a rectangular to circular adapters which were designed using octagonal transitions. The adapters were characterized to discount their effect on the OMT insertion loss measurements. Isolation was directly measured between ports 3 and 4 of the device while the circular input port was loaded.

Fig. 8 Measured and simulated insertion losses for the dual ridge OMT. We have assumed a conductivity of 3.5×10^{7} [S.m^{-1}] and a surface roughness of 2 μm for the aluminum walls of the OMT model.



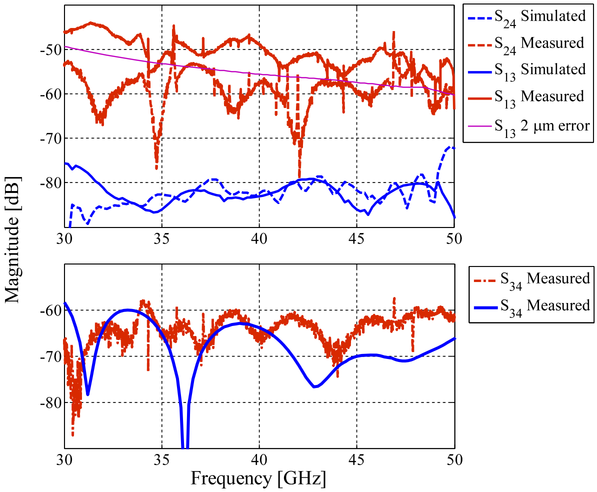


Fig. 9 Measured and simulated isolation (*bottom*) and cross-polar (*top*) for the dual ridge OMT. The cross-polar levels are well below −30 dB, which is according to specification. The difference between simulation and measurements in the cross-polar level is due to instrumental effects and to misalignments between the blocks that constitute the OMT. The isolation, in contrast, is similar to the simulated value of around −60 dB as it does not use any transitions when measuring.

Figures 7, 8 and 9 summarizes the simulations and experimental results. Except for cross-polar measurements, all set of results show an excellent agreement with the simulation, demonstrating the good quality of the fabricated OMT. The differences found in the cross-polar measurements can be explained by the cross-polar contribution of the adapters used to characterize the device and by a slight misalignment between the blocks that make the OMT. In fact, the measurements are consistent with simulations that incorporate a misalignment of 2–4 μm. It is important to notice that the misalignment does not affect any other of the S-parameters. Indeed, it only affects the cross-polar levels because it breaks the inherent symmetry of the OMT. Simulations also indicate that misalignment errors of up to 20 μm keep the overall cross-polar lower than −30 dB allowing this OMT to be scaled to higher frequencies keeping under control the alignment errors between blocks.

In the operation range of 31to 45 GHz we can summarize the results as follows:

(i) A return loss lower than −20 dB both at the H and V port (Fig. 7),
(ii) A transmission of about −0.4 dB (Fig. 8), and
(iii) Cross-polar and isolation of −50 dB and −60 dB respectively (Fig. 9).

It has to be noticed that the new design of the dual ridge OMT allows us to reduce the cross-polar levels previously published by [6] to −50 dB from the original −30 dB. This fact proves that this kind of devices can achieve a cross-polar as low as other reported waveguide OMTs [3, 4]. The new design also provides a compact and effective solution to interface the square waveguide inherent to the double ridge structure to the standard circular input needed to connect the horn.

Despite being optimized to work between 31 to 45 GHz, the OMT shows a good performance (return losses lower than −17 dB) between 30 to 48 GHz. With such performance this device is a good option for receivers covering the complete Q waveguide band (33-50 GHz).

4 Conclusions

A dual ridge OMT was designed to cover the ALMA Band-1 frequency range. The device was prototyped and tested showing an excellent RF performance all over the rather broad band of interest (37 %). Within this band the OMT reaches −20 and −45 dB of reflection and cross-polar level, respectively. In this way it improves previous results using the same technology and demonstrate that can achieve similar performance as other more popular waveguide OMTs but more difficult to be implemented. Moreover, the design shows good results out of the band of design, showing potential operation in a wider bandwidth. This is of particular interest for instruments that aim to cover the complete Q-band. Finally, the repeatability of the design is also outstanding, allowing the OMT to be used in projects, as it is the case of ALMA or future arrays of detectors, where a batch production of OMTs is needed.

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