Test of a Waveguide Orthomode Transducer for the 385-500 GHz Band

Alessandro Navarrini, Christopher Groppi, Robert Lin and Goutam Chattopadhyay

Abstract—**We report on the construction and test results of a waveguide Orthomode Transducer (OMT) for the 385-500 GHz band. The OMT is based on a symmetric reverse-coupling structure and consists of two copper alloy blocks in split-block configuration fabricated using numerically controlled (CNC) milling machining. Test results of a first prototype OMT employing standard UG387 flanges at all ports were described at the previous ISSTT Symposium. Here, we report on experimental results of a second OMT version utilizing custom made mini-flanges and much shorter input and output waveguides. This second OMT version is tolerant to misalignment errors of the block halves, has improved performance over the first prototype, and covers a wider band than initially specified. From 325 to 500 GHz the measured input reflection coefficient of the second prototype OMT was less than -10 dB, the transmission was ≈-1 dB, and the isolation was less than -30 dB at room temperature for both polarization channels.**

***Index Terms*—Orthomode transducer, polarization splitter, reverse coupling structure, waveguide components.**

I. Introduction

An Orthomode Transducer (OMT) is a passive device that separates two orthogonal linearly polarized signals within the same frequency band. An OMT has three physical ports but exhibits properties of a four-port device because the input common port, usually a waveguide with a square or circular cross-section, provides two electrical ports that correspond to the independent orthogonal polarized signals. Highly symmetric OMT structures are required to avoid the excitation of higher order modes and achieve broad relative bandwidths (up to 40% or wider.) Only few broadband waveguide OMT designs have been demonstrated to work well at frequencies greater than ≈100 GHz: the two-fold symmetric Bøifot junction [1]-[4] and its double-ridge variant [5]-[6], *b)* the four-fold symmetric turnstile junction [7]-[9], *c)* and the reverse-coupling waveguide structure [10]-[12]. In [12] we reported on test results of a first prototype reverse-coupling 385-500 GHz OMT with standard UG387 flanges; the design of a second OMT version with much shorter input and output waveguides, expected to be more tolerant to fabrication errors was also presented. Here, we report on fabrication and test results of that second OMT version which utilizes custom-made mini-flanges and has much improved performance over the first prototype.

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II. Design

The 385-500 GHz reverse-coupling structure OMT with short input and output waveguides (second version) is shown in Fig. 1. It is based on a 2 mm long square waveguide input (Port 1, 0.56x0.56 mm^2) and two single-mode waveguide outputs: a 4.8 mm long standard WR2.2 waveguide (0.56x0.28 mm^2) for Pol 2 (Port 3), and a 0.3 mm long oval waveguide with full-radius corners (external cross-section 0.62×0.28 mm^2) for Pol 1 (Port 2). The inner structure of the OMT consists essentially of: *a)* the square waveguide input that transitions to a 2.35 mm long full-height WR2.2 rectangular waveguide through a two-section transformer; the transformer is cascaded with a 90^0 E-plane rectangular-to-oval waveguide bend; *b)* two symmetric 90^0 waveguide hybrid couplers on the sidearms utilizing reactively terminated ports; *c)* an E-plane 180^0 waveguide hybrid (Y-junction) to recombine the out-of-phase signals from the two backward coupling structures. As a comparison, the longer waveguide sections in the first OMT prototype were: 11.3 mm for the

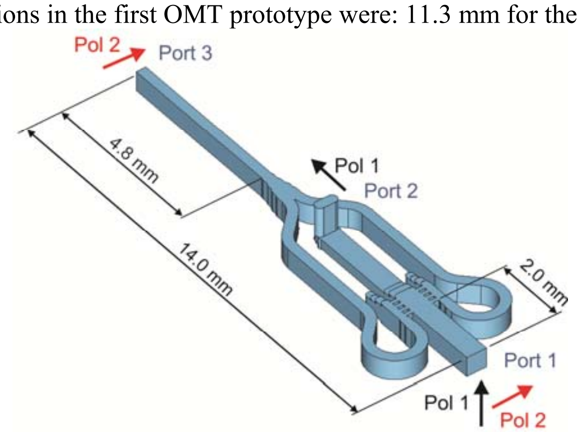

Fig. 1. Waveguide structure of the reverse-coupling OMT (second prototype with mini-flanges at all ports) showing the short square waveguide input (2 mm long) and outputs (0.3 mm long oval waveguide, 4.8 mm WR2.2 waveguide).

square waveguide input, 10.8 mm for the WR2.2 output and 1.0 mm for the oval waveguide output.

Results of the electromagnetic simulation of the OMT of Fig. 1, performed with a commercial software[1], were presented in [1].

III. Mechanical Blocks

The OMT consists of two mechanical blocks and is fabricated by splitting the structure of Fig. 1 along the E-plane of the side-coupled rectangular waveguides. The device has external dimensions 19 x 26 x 28 mm^3 and accepts mini-flanges at all ports. Circular pockets (diameter 20 mm) are machined into the blocks to reduce the waveguide lengths. Photographs of the assembled OMT and of its two unassembled blocks are shown, respectively in Fig. 2 and Fig. 3. The blocks were fabricated at Arizona State University (ASU) in 145 Copper alloy (unplated) using a Kern Micro numerically controlled milling machine. Photographs showing the internal details of the blocks are illustrated in Figs. 4. The blocks were aligned using two precision 1/16" diameter dowel pins. The tolerances for the waveguide channels in the two blocks and of the alignment between the blocks were specified at ± 5 μm. The blocks were bolted together by four 4-40 stainless steel screws. The achieved tolerances were all better than ± 3 μm.

Four 25.4 mm long waveguide transitions were also

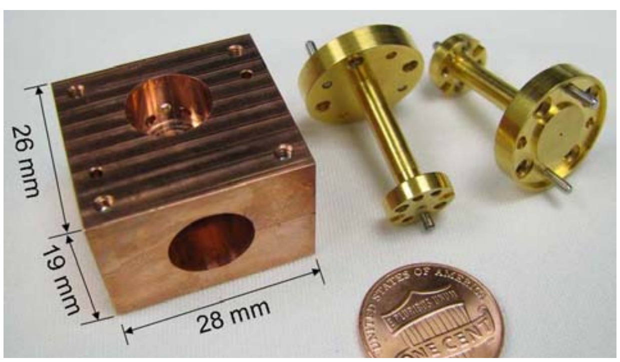

Fig. 2. Photograph of the assembled OMT (second prototype) with custom mini-flanges at all ports. Two of the test transitions with standard UG387 flange at one end and custom mini-flange at the other end are shown on the right.

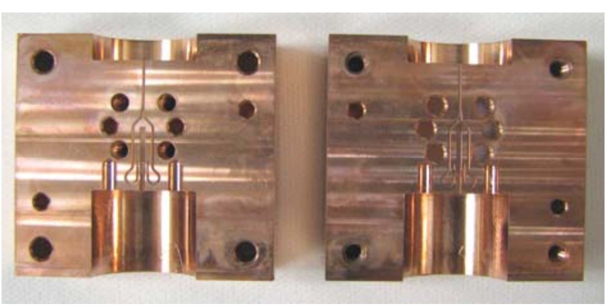

Fig. 3. Photograph of the two unassembled blocks of the OMT showing the internal waveguide circuitry.

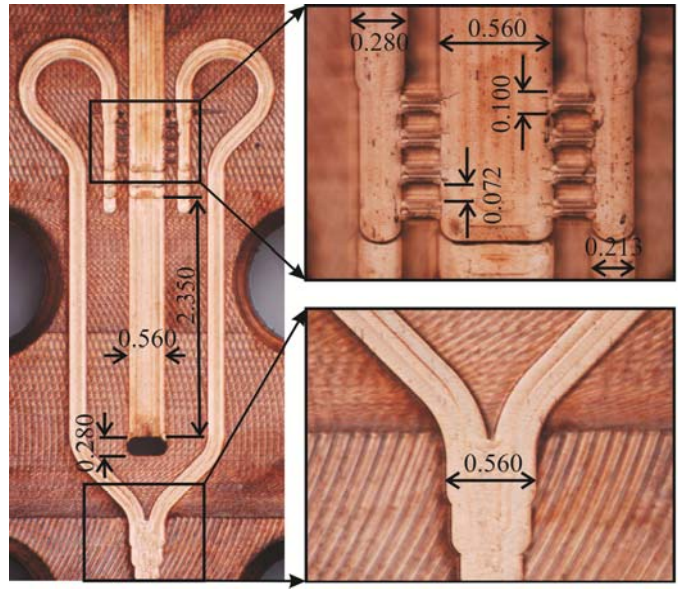

Fig. 4. Photograph of the internal circuitry of one of the two OMT blocks showing the dual-side reverse-coupling waveguide structure (close-up view on the upper right) and the details of the Y-junction power combiner (close-up view on the lower right.) The oval waveguide is visible on the left image.

fabricated[2] to allow testing of this second OMT version: *a)* two identical transitions linearly tapered from 0.56x0.56 mm^2 square waveguide to WR2.2 waveguide (employing custom mini-flange on the square waveguide and standard UG387 on the WR2.2 waveguide), and *b)* two identical straight sections of WR2.2 waveguide (employing custom-made mini-flange at one end and standard UG387 flange at the other end). Two of the test transitions (one of each type) are shown in Fig. 2.

IV. Experimental Results

The OMT was tested at JPL (Jet Propulsion Laboratory) using a Vector Network Analyser (VNA) consisting of a HP8510C Network Analyser and submillimeter-wave OML test set extensions. The VNA was calibrated at the WR2.2 rectangular waveguides outputs of the extension heads using two-port calibrations with WR2.2 calibration kit. The calibration procedure was used to remove systematic instrumental effects and to calibrate out the response of the instrument up to the chosen calibration planes. Additional measurements of the two pairs of identical back-to-back transitions allowed to calibrate out their individual losses and to derive the S-parameters of the OMT at the physical ports of the device.

A schematic of the Pol 2 transmission test setup is shown in Fig. 5. The square waveguide input of the OMT was attached to the WR2.2 waveguide port of the network analyser through the WR2.2 waveguide-to-square waveguide transition. The transition was oriented to excite the Pol 2 in the OMT. The WR2.2 waveguide output of the OMT was attached to the second WR2.2 waveguide port of the analyser through a straight section of WR2.2 employing a custom mini-flange on the OMT end and UG387 flange on the other end. The oval

[1] CST Microwave Studio, CST AG Bad Nauheimer Str. 1964289, Darmstadt, Germany, http://www.cst.com.

[2] Custom Microwave Inc, 24 Boston Ct, Longmont CO 80501 USA.

waveguide of the OMT was terminated with a matched WR2.2 waveguide load through a similar straight WR2.2 waveguide section for flange transition. The transmission measurement of the other polarization channel was obtained with a setup similar to the one in Fig. 5 but with WR2.2 waveguide-to-square waveguide transition rotated by 90^0 to excite Pol 1 at the OMT input and with waveguide matched load and second port of the analyser swapped at the OMT outputs. A photograph of the transmission test setup of Pol 2, equivalent to that of Fig. 5, is shown on Fig. 6.

All measurements were performed across the frequency band 325-500 GHz. Experimental results are presented in Figs. 7-9, where a vertical line at 385 GHz indicates the nominal lower band edge of the design.

The measured transmissions of the OMT are illustrated in Fig. 7; the values are larger than -2.5 dB across 325-500 GHz with averages of order -1 dB for both polarization channels (the level predicted by the electromagnetic simulation was ~-0.2 dB for Pol 1 and ~-0.6 dB for Pol 2 when using an electrical conductivity $\sigma=5.8 \cdot 10^7\ \Omega^{-1}\mathrm{m}^{-1}$, same as the dc conductivity of Copper at room temperature). The transmissions of individual test transitions are also shown in Fig. 7.

The reflection coefficients at the OMT input were measured by terminating the OMT outputs with WR2.2 matched loads.

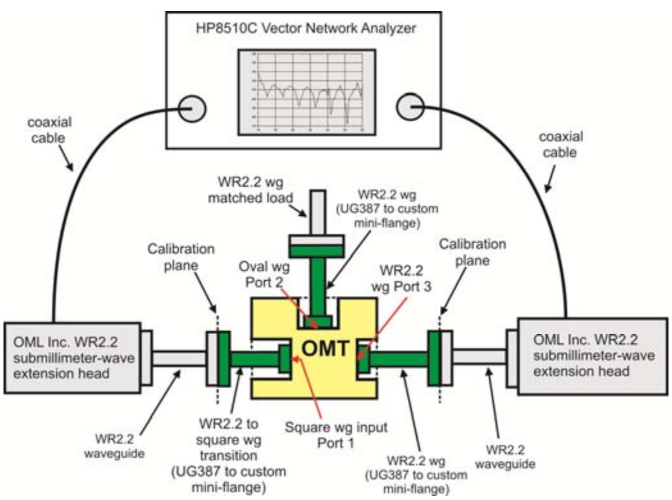

Fig. 5. S-parameter measurement of the OMT with sub-millimeter wave VNA. The particular configuration refers to the transmission measurement of Pol 2.

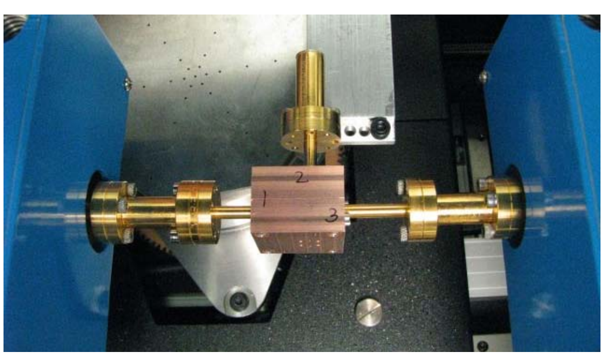

Fig. 6. Photo of the OMT during Pol 2 transmission measurement with the sub-millimeter wave VNA.

The amplitude of the measured reflection is below -10 dB for both polarization channels (Fig. 8.) The effects of reflection from the waveguide test transitions (of order up to -15 dB) could not be removed from these measurements. Therefore, the plots of Fig. 8 provide only an order of magnitude of the OMT input reflection.

An estimate of the isolation was obtained by measuring the transmissions from the OMT output ports with its square waveguide input open to free space. This gives an upper limit of the isolation of the device. The measured isolation is below -30 dB (Fig. 9.)

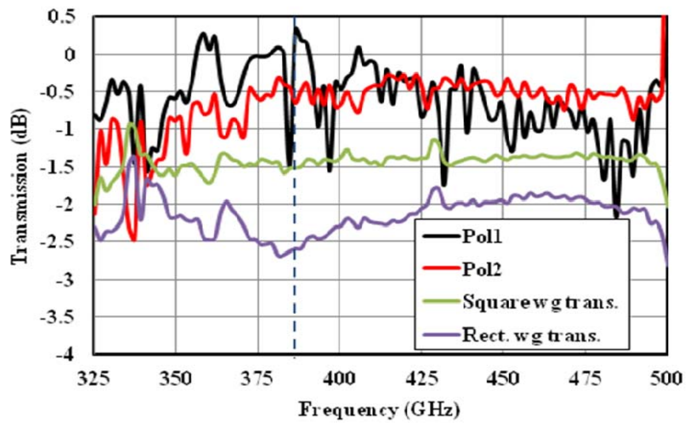

Fig. 7. Measured transmissions of the OMT prototype (at room temperature) and of individual test transitions.

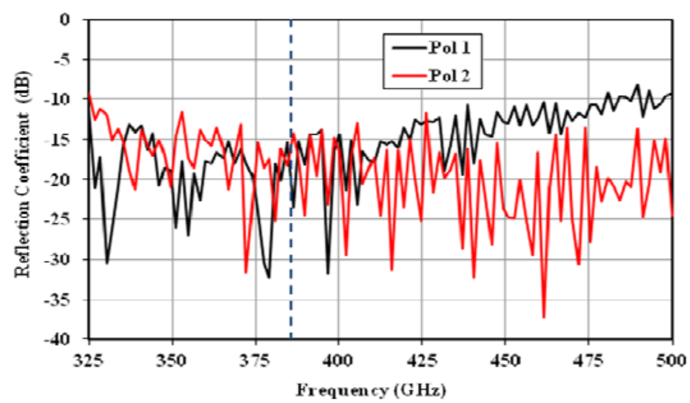

Fig. 8. Measured input reflections of the OMT.

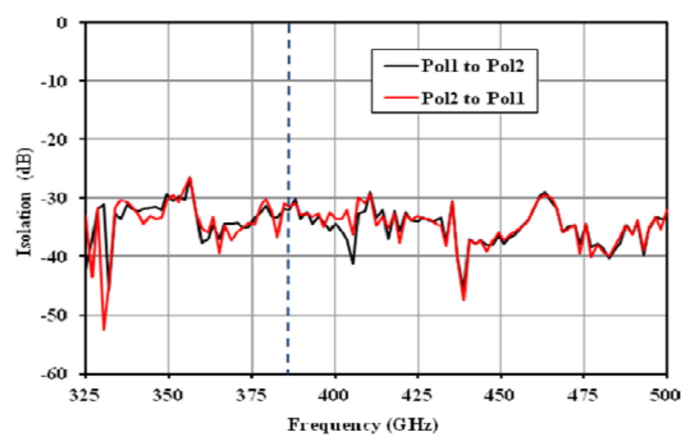

Fig. 9. Measured upper limit of the isolation of the OMT: transmission between output ports with square waveguide input open to free space.

The cross-polarization of the OMT is the transmission from one polarization channel at the square waveguide input to the unwanted output channel when the other two electrical ports of the four electrical ports device are terminated into matched loads. We estimated the cross-polarization of the OMT by using a transmission setup similar to the one in Fig. 5, except that the square waveguide-to-rectangular waveguide transition connected to the VNA port (on the left of Fig. 5) was rotated to excite Pol 1 at the square waveguide OMT input; the transmission to the "unwanted" OMT output in WR2.2 waveguide (Port 3) gives an order of magnitude for the cross-polarization of this polarization channel. The cross-polarization of the OMT second polarization channel was estimated by injecting Pol 2 at the OMT square waveguide and by extracting the signal from the oval waveguide (with WR2.2 port terminated into a matched load). Although this method does not directly measure the OMT cross-polarization (the non-excited polarization channel at the OMT square waveguide is not matched when a rectangular to square waveguide transition is connected at its input) it can be used to provide a good estimate of it. The average values of the OMT measured cross polarization levels were approximately -23 dB across 325-500 GHz for both polarization channels. This is a major improvement over the cross-polarizations of the first OMT prototype [12], whose average values were of order -12 dB and -15 dB.

We found that the adopted measurement method of the OMT cross-polarization was not very accurate because: *a)* it was very sensitive to small imperfections, due to mechanical tolerances, of the custom mini-flanges at the interface between the square waveguides of OMT and test transition, and *b)* the intrinsic cross-polarization of the test WR2.2-to-square waveguide transitions was limited. Therefore, we expect the cross-polarization of the OMT to be actually better than the reported value of ~-23 dB.

V. Conclusion

A waveguide OMT based on a reverse-coupling structure with short input and output waveguide was fabricated and tested. The OMT performs well over a wideband, 325-500 GHz, larger than the one of design. The OMT is more tolerant to misalignment errors than a previous prototype version which was based on a much longer square waveguide input and longer WR2.2 output. The second OMT version has insertion losses approximately half of the first prototype and an improved isolation level.

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