Test of 1 mm Band Turnstile Junction Waveguide Orthomode Transducer

Alessandro Navarrini, Alberto Bolatto, and Richard L. Plambeck

Abstract—**We tested five prototype waveguide orthomode transducers (OMTs) designed for the 200-270 GHz frequency band. These OMTs, based on a turnstile junction, have identical designs [1], but were fabricated by different manufacturers using different techniques and materials. The OMTs were tested at NRAO, Charlottesville, using a Vector Network Analyzer (VNA) in the frequency range 210-310 GHz. Three of the OMTs have average room temperature insertion loss of ~1 dB or better, average input and output reflection of approx –18 dB, and cross-polarization and isolation of order –30 dB over 210-270 GHz.**

The integrity of the tuning stub in the turnstile junction is the key for good performance: a gap between the quadrants there causes additional losses up to several tenths of a dB. Filling up the gap with indium gave, for the OMT with best performance, a transmission loss better than –0.8 dB over the entire 210-290 GHz band. Input and output reflections are better than –12 dB, with cross-polarization and isolation better than –25 dB across the same band.

Index Terms— **Radio astronomy, Turnstile junction, Power combiner, Polarimetry, Waveguide transitions**

I. Introduction

We are constructing OMTs for dual polarization 200-270 GHz receivers on the CARMA array. The design of the OMT is discussed in [1] and [2]. The device has a circular waveguide input (diameter 1.12 mm) and two WR3.7 rectangular waveguide outputs (0.94 mm x 0.47 mm.) The OMT, illustrated in Fig. 1, utilizes a turnstile junction and two E-plane power combiners [3]. A tuning stub located at the base of the circular waveguide matches the input over a full frequency band.

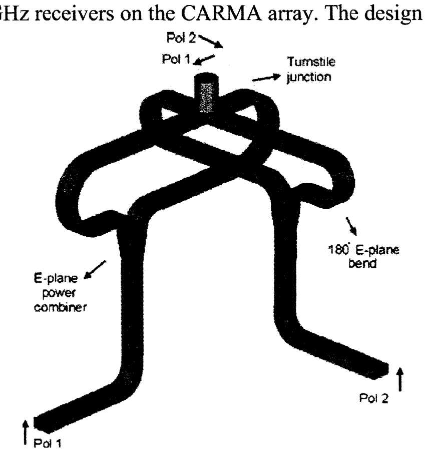

Fig. 1. Internal view of the full OMT. Opposite ports of the turnstile junction are brought together with E-plane bends and power combiners.

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II. Mechanical Blocks

The OMT is constructed by dividing the structure of Fig. 1 into four blocks that intersect along the circular waveguide axis. The tuning stub at the base of the turnstile junction is split into four identical sections that are machined at the same time as the rectangular waveguides. The OMT, shown in Fig. 2, accepts a standard UG387 flange at its input so it can mate with our existing feed-horns. Custom mini-flanges are used for the WR3.7 output waveguides of the OMT for compactness of the device. The mini-flanges are identical to those of the ALMA Band 6 OMTs and SIS mixers, where the

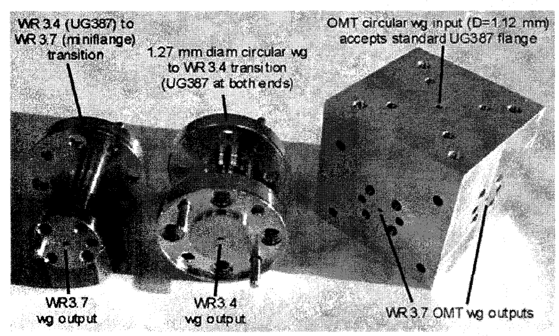

Fig. 2. View of assembled OMT (on the right) with the circular waveguide input on top and the two WR3.7 waveguide outputs with custom mini-flanges. Two of the 19.05 mm long transitions used for testing are shown to the left of the OMT.

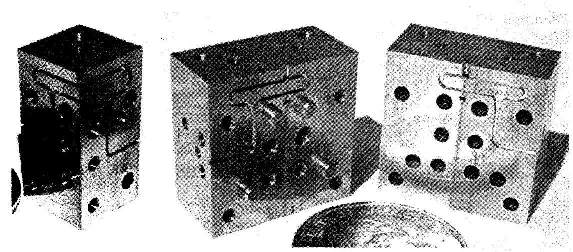

Fig. 3. OMT n. 2 machined at RAL. Left) View of one of the four quarters. Right) View of assembled mating pairs of blocks showing the waveguide circuitry for Pol 2.

alignment pins and screw holes are on a 7.11 mm diameter bolt circle. Our OMT is a cube 23 mm on a side. The electrical path length from the circular waveguide at the input of the OMT to the WR3.7 waveguide outputs is ~28 mm for Pol 1 and ~30 mm for Pol 2.

Fig. 3 shows photos of one of the four blocks and of the mated block pairs. Details of the internal waveguide circuitry of the OMT are shown in the photos of Fig. 4. Five OMTs of identical design were fabricated by different manufacturers using different materials and machining techniques. Their main features are summarized in Table 1. Measurement results allowed to compare OMTs performance in relation to mechanical tolerances.

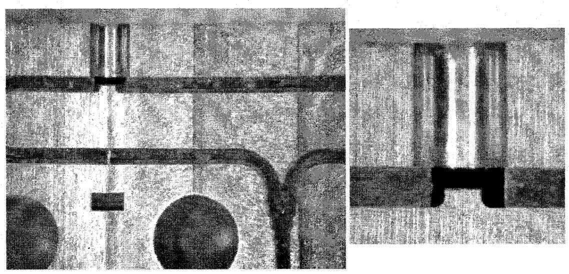

Fig. 4. OMT n. 5 machined at Univ. of Arizona. View of an assembled mating pair of blocks showing the internal waveguide circuitry of turnstile junction, and power combiner (on the left), and the details of the tuning stub at the turnstile junction circular waveguide base (on the right).

TABLE I

OMT n.	Machined by	Material	Notes
1	RAL, Berkeley, CA	Aluminum	Four blocks machined from a single bar
2	RAL, Berkeley, CA	TeCu	Four blocks machined from a single bar
3	Protofab, Petaluma, CA	TeCu	Blocks machined individually
4	Custom Microwave Inc., Longmont, CO	Gold plated brass	Blocks machined individually
5	Univ. of Arizona, Tucson, AZ	Gold plated brass	Blocks machined individually.

The four blocks of OMTs n. 1 and n. 2 were machined in our own shop (RAL) at one time as part of a single 12.7 x 12.7 x 165 mm^3 metal bar using a numerically controlled milling machine (CNC Tree Journeyman 350 equipped with high speed Astro-E500 spindle 50000 rpm.) Inspection of the blocks with the optical microscope showed that the maximum offset between rectangular waveguide cuts in block halves is approximately 0.040 mm. The four blocks of the other three OMTs were fabricated individually using machines capable of achieving better accuracy. The maximum offset between waveguide cuts in block halves of OMT n. 5, fabricated at University of Arizona using a Kern Micro milling machine, was less than 0.015 mm. Unfortunately, the tuning stub and one of the power combiners of such OMT were slightly damaged after we sent it out the for gold plating.

III. Measurement Setup

We tested the five OMTs during the week 24-28 October 2005, at NRAO, Charlottesville, using an Agilent 85106C Vector Network Analyzer (VNA) equipped with Oleson WR3.4 millimeter-wave test set extensions. A schematic of the cross-polarization test setup is shown in Fig. 5.

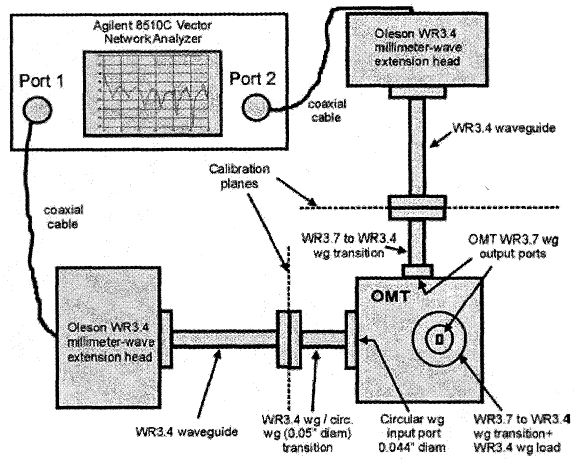

Fig. 5. S-parameter measurement of the OMT with the VNA. The particular configuration refers to the cross-polarization measurement.

The VNA was calibrated at the WR3.4 waveguide at the outputs of the extension heads using a two-port TRL calibration with Oleson WR3.4 calibration kit. A Custom Microwave transition from WR3.4 rectangular waveguide to 1.27 mm diameter circular waveguide (Fig. 2) was attached to the 1.12 mm circular waveguide input of the OMT. Although the locating pins of the OMT input flange are on the normal 14.27 mm diameter bolt circle, it was not possible to locate the waveguide screws in their normal positions, so a special aluminum clamp was made to bolt the OMT to the flange of the transition (Fig. 6.)

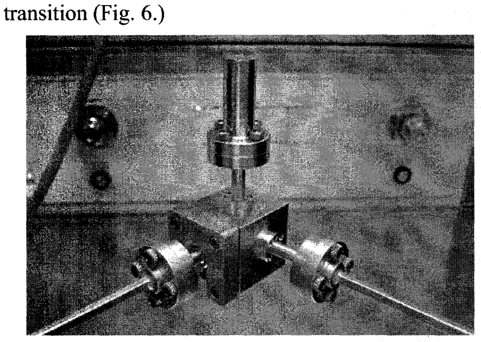

Fig. 6. Pol 1 transmission measurement of the OMT with the VNA. An aluminum clamp is used to attach the WR3.4 to 1.27 mm diameter circular waveguide transition at the input of the OMT (on the left.) One of the OMT WR3.7 output is attached to the WR3.4 waveguide connected to the mm-wave extension head of the VNA through a WR3.7 to WR3.4 transition (on the right.) The second OMT WR3.7 output (on top) is terminated into a WR3.4 waveguide load through a WR3.7 to WR3.4 transition. A single two-port measurement in this configuration provides the direct and reverse transmission as well as the input and output reflection of the OMT with transitions.

IV. Experimental Results

We tested the OMTs between the minimum operating frequency of the VNA, 210 GHz, up to 310 GHz. This range overlaps with most of our OMT design band, 200-270 GHz. Between 210-215 GHz the measurements have a higher noise level because of the lower power level of the VNA in that frequency range.

A. Tuning stub fix

Tests of the OMTs showed that their good performance depends on the integrity of the tuning stub located at the base of the circular waveguide. Three of the OMTs had small imperfections and gaps between quadrants at the tuning stub. After filling the gap with indium, the insertion loss improved by several tenths of a dB in most cases. Fig. 7 shows photos of the tuning stub of OMT n. 3 before and after fix. Fig. 8 shows that the transmission of both polarization channels of that OMT improved from an average value across the band of ~1 dB to a value of ~0.6 dB, which is similar in overall level to the value predicted by the electromagnetic simulation. The measured room temperature transmission is above –0.8 dB across 210-290 GHz. After tuning stub fix, the average insertion loss of three of the OMTs was ~1 dB or better across the same band.

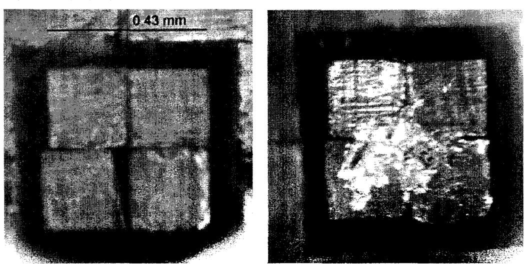

Fig. 7. Magnified top view of the tuning stub before (left) and after (right) filling up the gap with indium of OMT n. 3. After tuning stub fix, the value of insertion loss of this OMT improved by approximately 0.4 dB across the band.

The input reflection and cross-polarization measurements of OMT n. 3 after tuning stub fix are given in Fig. 9. The input reflections, unchanged after the fix, are below –12 dB across 210-290 GHz. The small differences between the measured reflection coefficients for the two polarization channels indicate that they are electrically very similar. The output reflections are similar, in overall level and shape, to those at the input. The cross-polarization and isolation levels are both below –25 dB; one of the two polarization channels improved by ~5 dB after fix, bringing the average levels across the band from –30 dB down to –35 dB.

B. Transmission resonances

Two of the OMTs had problems, showing narrow and deep transmission resonances in the band of interest. Fig. 10 shows the measured transmission of OMT n. 2 with deep resonances below the –4 dB level. Experiments with a K-band scale model of the OMT indicate that these resonances are probably related to fabrication errors that cause a misalignment of one (or more) of the four quarters of the OMT.

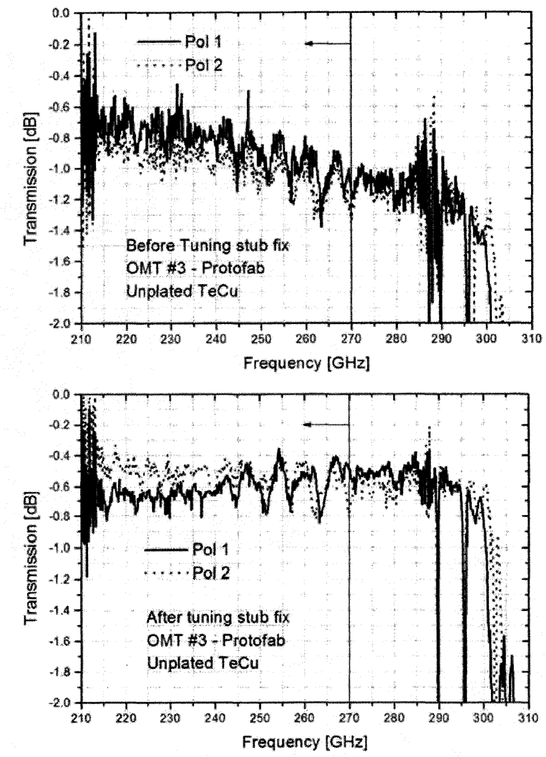

Fig. 8. Pol 1 and Pol 2 transmission measurement of OMT n. 3 before (top) and after (bottom) tuning stub fix. The vertical line in the graphs delimits the nominal highest frequency of the band at 270 GHz.

A difference in the electrical length of opposite waveguide arms between the turnstile junction and the power combiner causes the appearance of a series of resonances in the transmission of the OMT. Energy coming from the turnstile junction reflects back from the power combiner when the two signals reaching it are not exactly 180^0 out of phase. Electromagnetic simulations of the three-port model of Fig. 1 with imbalanced waveguide sidearm lengths, performed with CST Microwave Studio [4], confirm the appearance of deep transmission resonances across the band. The depth of the resonances increases with sidearm length difference; an increase in the waveguide losses makes the resonances shallower and broader. Resonances in the transmission of the OMT are also expected when the physical lengths of the two waveguide sidearms are identical, but one of the sidearms has a different electrical length from the other: an offset along the midplane of the rectangular waveguides caused by a lateral misalignment of block halves changes the propagation constant (and hence the phase velocity) with respect to a waveguide with no offset. Thus, if one of the four blocks of the OMT is offset along the circular waveguide axis, the two waveguide sidearms of each polarization channel will have different electrical lengths. Because of the different physical length of WR3.7 waveguide sections in different blocks, the

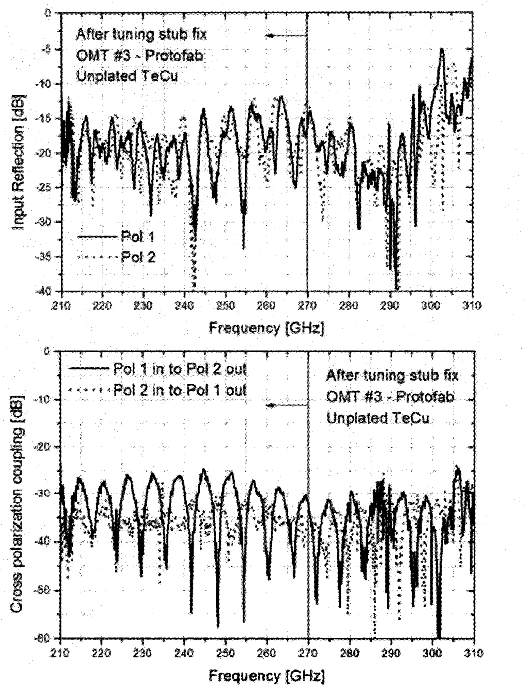

Fig. 9. Pol 1 and Pol 2 input reflection (top), and cross polarization coupling (bottom) of OMT n. 3 after tuning stub fix.

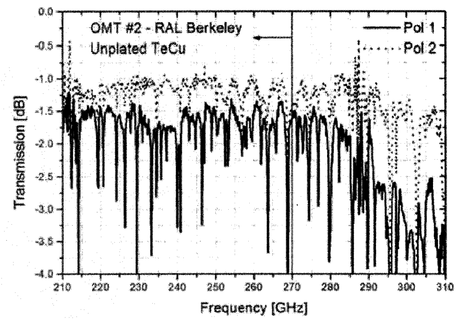

Fig. 10. Pol 1 and Pol 2 transmission of OMT n. 2.

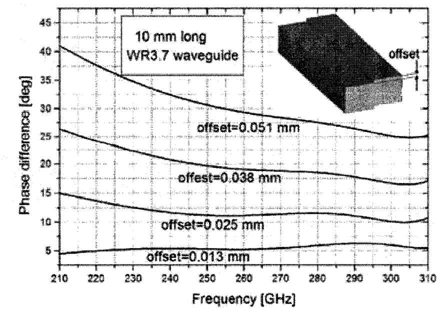

Fig. 11. Transmission phase differences between a straight 10 mm long WR3.7 waveguide and a same length waveguide section where block halves are offset by 0.013 mm, 0.025 mm, 0.038 mm, 0.051 mm.

electrical length difference depends on which one of the four blocks is offset with respect to the others. For example, an offset of the block having the shortest waveguide cut sections (the one without power combiners), causes an offset along the midplane of an ~10 mm long section of WR3.7 waveguide associated with the polarization channel n. 1 on one of the lateral sidearms, but not on the other (the physical length of the sidearms between the turnstile junction and the power combiner is ~14 mm and ~13 mm for polarization channels 1 and 2, respectively.) To give an estimate of the electrical length difference between two sidearms caused by an offset of one of the blocks along the axis of our OMT, we performed electromagnetic simulations of: *a*) a straight 10 mm long section of WR3.7 waveguide; *b*) a same length waveguide laterally misaligned along the midplane (see Fig. 11.) The difference between the phase of the two transmissions is ~12 deg at 230GHz for an offset of 0.025 mm. At the same frequency, the phase difference between two WR3.7 waveguides (with no offset) with length difference 0.025 mm is ~5 deg, less than half that value. Therefore, a given amount of misalignment of one of the blocks along the circular waveguide axis (caused, for example, by loose locating pins) is expected to be more harmful to the OMT performance than fabrication errors causing the same amount of length difference between turnstile junction waveguide sidearms. A design of the OMT that minimizes the physical length difference between WR3.7 waveguide sections in different blocks should help reduce this problem.

V. Conclusions

We tested five prototype turnstile junction waveguide orthomode transducers for the 1 mm band. Three of the OMTs have average room temperature insertion loss of ~1 dB or better, average input and output reflection of about −18 dB, and cross-polarization and isolation of order −30 dB over 210-270 GHz. The performance of the OMTs improved after filling small gaps between quadrants at the turnstile junction tuning stub with indium: the insertion loss decreased by several tenths of a dB across the band. The OMT that gave best performance has insertion loss better than 0.8 dB across 210-290 GHz.

VI. Acknowledgements

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References

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