A Compact Full Waveguide Band Turnstile Junction Orthomode Transducer

***Sivasankaran Srikanth*[1] *and Michael Solatka*[2]**

[1, 2] National Radio Astronomy Observatory, 1180 Boxwood Estate Road, Charlottesville, VA 22903 USA

434-296-0328 (phone) and 434-296-0324 (fax)

[1]ssrinkant@nrao.edu, [2]msolotka@nrao.edu

Abstract

This paper describes the development, construction, and measurement of a full waveguide band (8-12 GHz) orthomode transducer (OMT). The design uses a turnstile junction at the input, two 90° H-plane bends in each of four waveguide arms, and two E-plane Y-junctions. The outputs are in WR90 waveguides. Measured return loss is better than 19 dB and cross polarization lower than -50 dB in the 7.8-12.2 GHz range. Three large aluminum blocks form the main body of the OMT. The device has a diameter of 8.0”, height of 2.7”, and weighs 2.5 lbs.

1. Introduction

An orthomode transducer (OMT) is a passive microwave device that separates two orthogonal, linearly polarized signals within the same frequency band. Orthomode transducers are essential components of feed systems in radio astronomy and high capacity communications applications. Cryogenically cooled broadband receivers are commonly used in radio telescopes that operate over frequency ranges of a few orders of magnitude. OMTs used in such applications are essentially broad in bandwidth, possess good input match, low loss, and are compact to keep thermal load a minimum. In addition, good isolation between the output ports and low cross polarization coupling are essential.

The receivers on the Expanded Very Large Array (EVLA) [1] of the National Radio Astronomy Observatory (NRAO) use three different kinds of polarizer. The receivers at L- (1-2 GHz), S- (2-4 GHz), and C- (4-8 GHz) bands use broadband quad-ridge OMTs [2]. The Ku- (12-18 GHz), K- (18-26.5 GHz) and Ka- (26.5-40 GHz) band OMTs make use of the Bøifot junction [3], [4]. The length of this type of OMT is ~5.5 free-space wavelengths (λ) at the center frequency. The Q-band (40-50 GHz) receiver uses a septum polarizer [5] which is narrower in bandwidth. The fabrication complexity of the quad-ridge OMT and the large size of the Bøifot Junction OMT motivated the development of a more compact polarizer for the X-band (8-12 GHz) receiver.

The Bøifot junction OMT uses a two-plane symmetry resulting in broadband performance. In the Bøifot design, two ports that form the main-arm are separated by a septum. The side-arm ports have pins that provide a low impedance path for the main-arm wall currents. The OMT presented in this paper does not have the septum or the pins, which makes fabrication relatively simple, especially with the requirement for a large number (~30) for the EVLA project. Several variations of OMTs based on turnstile junction [6]-[9] have been described in the literature. The OMT of Aramaki et al. [6] uses a pyramidal tuning element at the base of the junction, has circular input port, and has an input return loss >19 dB over the 10.6-15 GHz range. The OMT described here is similar to the one presented by Aramaki, that it uses 90° H-plane bends and E-plane Y-junctions. However, it utilizes a turnstile junction with a square prism tuning element resulting in a broader bandwidth (>1.5:1), has square input port, and a novel mechanical design. The OMTs in [7]-[9] use 180° E-plane bends and are narrower in bandwidth (1.46:1).

2. Geometry

The X-band OMT presented in this paper has a square input waveguide 0.900” x 0.900”. The turnstile junction has four WR90 (0.900” x 0.400”) output ports. A metallic tuning element at the base of the square waveguide provides excellent input match over the entire 8-12 GHz band. The element is a square prism with 0.335” x 0.335” base and 0.210” height.

Fig. 1 shows the geometry of the OMT. Each output port of the turnstile junction goes through two 90° H-plane bends before a pair of opposing arms is joined in an E-plane Y-junction. To allow two of the arms to cross without interference, stepped transformers are located before the cross-over to reduce the height of the waveguide from 0.400” to 0.180”. In order to preserve symmetry, the other two arms also have identical stepped transformers. Each

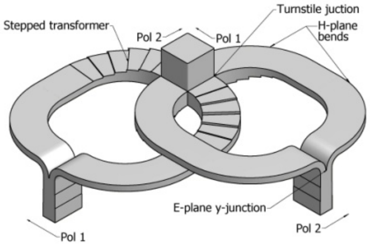

Fig. 1: Internal geometry of the OMT

978-1-4244-6051-9/11/$26.00 ©2011 IEEE

polarization splits equally at the turnstile junction and couples into two opposite ports with a 180° phase difference and when combined in the Y-junction, the two components add constructively. The output of the Y-junction also has a stepped transformer where the waveguide height increases from 0.380" to 0.400". In addition to the fundamental TE_{10} and TE_{01} modes, the square waveguide can propagate the TE_{11} and TM_{11} modes in the 8-12 GHz band. These modes are degenerate and have a cut-off frequency of 9.272 GHz. However, these higher order modes are not excited because of the two-plane symmetry of the structure.

3. Design and Optimization

Design of the various sub-components of the turnstile junction OMT was optimized individually. The turnstile junction by itself has poor reflection coefficient since sharp bends intrinsically have poor matching characteristics. Metallic tuning elements have been used effectively at the base of the junction to improve the matching properties. Different shapes were tried and optimized using CST Microwave Studio electromagnetic simulator [10]. The simulated reflection coefficient for the fundamental TE_{10} mode of the turnstile junction with tuning elements of different shapes is shown in Fig. 2. A square prism, with dimensions 0.335" x 0.335" x 0.210" and a return loss of ≥21.6 dB, was chosen.

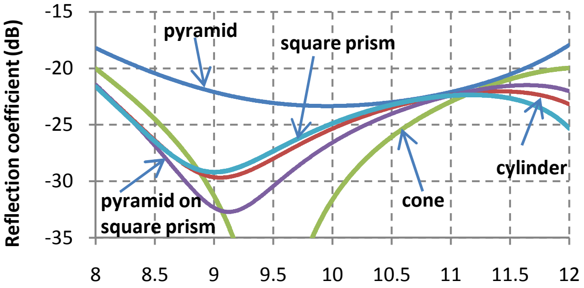

Fig. 2: Simulated S_{11} of the turnstile junction with different tuning elements

The rectangular waveguide from each port of the turnstile junction goes through two 90° H-plane bends before termination at the Y-junction. For low reflection coefficient over a waveguide band, de Ronde [11] formulation of bends is used. In order to keep the size of the OMT relatively small and insertion loss low, a center radius of 1.648" is used for the H-plane bends resulting in return loss ≥30 dB. The waveguide heights are reduced from 0.400" to 0.180" in a five-step quarter-wave Tchebyshev transformer. The computed reflection coefficient of the H-plane bends with the stepped transformer is ≥30 dB. The steps were machined with a 0.047" diameter end-mill. The tool radii at the sidewall junctions were included in the simulation model.

The E-plane Y-junction has a center radius of 0.350" and center off-set distance of 0.450" from the center of the junction, resulting in a 0.020" wide cusp at the junction of the curved arms. The waveguide at the output of the junction has a height of 0.380". A two-step transformer is used to transition to the full height of 0.400" for the output waveguide. The simulated reflection coefficient of the Y- junction is ≥32.6 dB.

A global model of the OMT obtained by joining the various sub-components that were individually optimized was solved using the Microwave Studio simulator. The solver accuracy was set at -40 dB. Material properties of aluminum were used in the simulator model. The model used in the simulation accounts for all the end-mill radii at the steps and at the corners of the square input port. Fig. 3 shows the simulated reflection coefficient at the square port for one of the polarizations for the full OMT and is ≥19 dB in the 8-12 GHz range. The reflection coefficient for the other polarization is identical. The insertion loss varies between 0.05 dB and 0.15 dB as shown in Fig 3. Simulated cross polarization coupling ≥45dB.

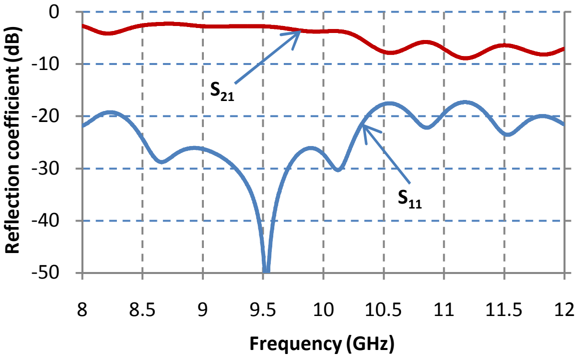

Figure 3: Simulated S-parameter of the full OMT

4. Mechanical Design

The main body of the OMT is composed of three major blocks, as shown in Fig. 4. The center block has the opening for the square port, two side ports of the turnstile junction, and the associated side arms with the stepped transformer on the top side. The bottom side has the other set of side ports with the associated waveguide arms. The top block has the square port opening and forms the top wall of the top waveguide arms. The tuning element is machined on the bottom block so that it is at the center of the square port. This block also forms the bottom wall of the lower waveguide arms. The two Y-junctions are of split-block construction. The Y-junction assemblies are a snug fit in the openings of the main body assembly. Guides and stops on the Y-junction assembly ensure alignment of the waveguides in the Y-junction and the main body. The different parts of the OMT were machined on a numerically controlled machine to an accuracy of ±0.0005”. The OMT has a cross-section of 8.0” diameter and height of 2.7”. The weight of the prototype OMT is 2.5 lbs.

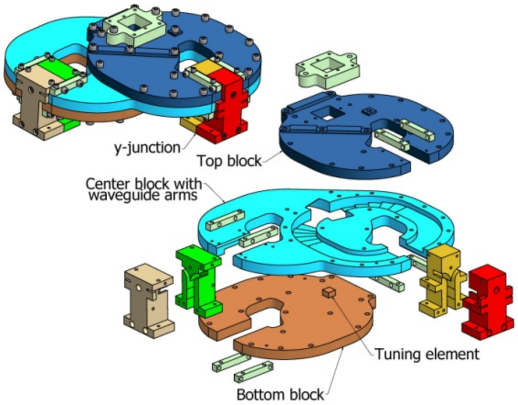

Fig. 4: Assembled OMT and sub-components

5. Measurements

The S-parameters of the OMT were measured using an Agilent N5245 PNA analyzer. Measurements were done in two bands: 7.5-11.5 GHz and 8.5-12.5 GHz with two different sets of coax-to-waveguide adapters. The square port was connected to the analyzer through a square-to-rectangular waveguide transition. The rectangular port of the OMT not connected to the analyzer was terminated with a HP termination X910B, which has a return loss ≳45 dB. Fig. 5 shows the combined results from the two measurements of the reflection coefficient and insertion loss for the two orthogonal polarizations. Measured results are similar to the simulation shown in Fig. 3 and the small differences in the reflection coefficient plots are caused by the square-to-rectangular transition included in the measurement. The insertion loss shown in Fig. 5 has been corrected for the loss of the square-to-rectangular transition included in the measurement. Insertion loss of the OMT varies between 0.05 and 0.15 dB.

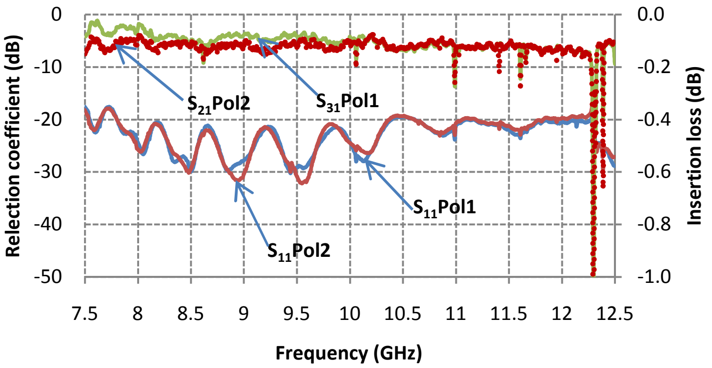

Fig. 5: Measured reflection coefficient and insertion loss

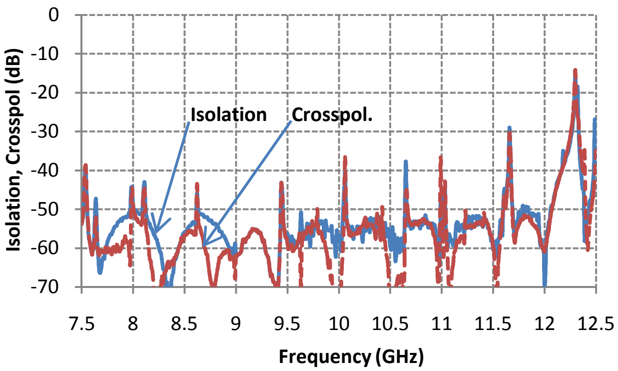

Fig. 6: Measured cross polarization coupling and isolation

Cross polarization coupling is measured by exciting the square port with one polarization and measuring the coupling in the isolated rectangular port, while the other rectangular port is terminated in a matched load. Measured cross polarization coupling is ≥50 dB from 7.5-12.2 GHz, as shown in Fig. 6. Isolation between the rectangular ports is measured by connecting the two ports to the analyzer, while the square port is terminated in a load. Measured isolation is ≥50 dB from 7.5-12.2 GHz and is shown in Fig. 6. The resonances seen are reflections caused by misalignment of the waveguides used in the measurement. Use of aligning pins and absorbing vane in the square-to-rectangular transition would minimize these resonances.

6. Conclusion

A full waveguide band (8-12 GHz) OMT has been designed, fabricated and tested. The OMT is based on a turnstile junction with a square prism tuning element and has measured return loss ≥19 dB for both polarizations from 7.8-12.2 GHz. Measured insertion loss is <0.15dB and isolation between the two orthogonal ports is ≥50 dB. The alignment of the waveguides in the main body and the Y-junctions is critical to the proper functioning of the OMT. Wall-to-wall contact between these sub-assemblies is also important. The mechanical design ensures precise alignment between the waveguides and easy assembly.

The machining and assembly skills of M. Meek of the NRAO machine shop are greatly appreciated. The guidance and assistance provided by J. Ruff and G. Morris are acknowledged. The authors also thank A. R. Kerr, P. Ward, and M. Mayo for assisting in the manuscript preparation.

References

[1] R. Perley, P. Napier, J. Jackson, B. Butler, B. Carlson, D. Fort, P. Dewdney, B. Clark, R. Hayward, S. Durand, M. Revnell and M. McKinnon, “The Expanded Very Large Array,” *Proceedings of the IEEE, Special Issue on Advances in Radio Astronomy*, vol. 97, no. 8, pp1448-1462, August 2009.

[2] G. M. Coutts, H. Dinwiddie and P. Lilie, “S-Band Octave-Bandwidth Orthomode Transducer for the Expanded Very Large Array,” *2009 IEEE AP-S International Symposium Digest*, vol. 2, pp 383-387, June 2009.

[3] A. M. Bøifot, E. Lier and T. Schaug-Pettersen, “A Simple and Broadband Orthomode Transducer,” *IEE Proceedings*, vol. 137, No. 6, pp 396-400, December 1990.

[4] E. Wollack, “A Full Waveguide Band Orthomode Junction,” EDIR No. 303, National Radio Astronomy Observatory, May 1990.

[5] E. Salzberg, “Microwave hybrid polarizer,” US Patent 4122406, Issued October 24, 1978.

[6] Y. Aramaki, N. Yoneda, M. Miyazaki and T. Horie, “Ultra-thin Broadband OMT with Turnstile Junction,” *2003 IEEE MTT-S International Microwave Symposium Digest*, vol. 1, pp 47-50, June 2003.

[7] A. Navarrini, R. L. Plambeck, and D. Chow, “A Turnstile Junction Waveguide Orthomode Transducer for the 1mm Band,” *Proc. ISSTT*, pp. 519-523, May 2005.

[8] A. Navarrini and R. L. Plambeck, “A Turnstile Junction Waveguide Orthomode Transducer,” *IEEE Trans. Microwave Theory Tech*., vol. 54, no. 1, pp. 272-277, January 2006.

[9] G. Pisano, L. Pietranera, K. Issak, L. Piccirillo, B. Johnson, B. Maffei, and S. Melhuish, “A Broadband WR10 Turnstile Junction Orthomode Transducer,” *IEEE Trans. Microwave and Wireless Components Letters*, vol. 17, no. 4, pp. 286-288, April 2007.

[10] CST Microwave Studio, Headquarters: Darmstadt, Germany.

[11] F.C. de Ronde, “Full Band Matching of Waveguide Discontinuities,” *MTT-S Int. Microwave Symp. Digest*, Palo Alto, CA, 1966.