Design of a Ultra Wideband Ridged Waveguide Turnstile Orthomode Transducer for mm-Wave Radio Astronomy Applications

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Abstract— **Ridged waveguide technology is applied to design a wideband turnstile orthomode transducer (OMT) for radio astronomy applications. The OMT features a quad-ridged circular input waveguide that supports dual-polarization. It includes two single-ridged rectangular waveguide output ports. The design incorporates a two-fold symmetric turnstile junction at the input, facilitating effective mode coupling. An intermediate section with cylindrical components is used for impedance matching. The turnstile junction is connected to a ridged T-junction combiner via E-plane bends. The performance of the OMT is evaluated using two full-wave electromagnetic simulation tools, CST Microwave Studio and HFSS. Operating over a frequency range of 65–165 GHz, the OMT demonstrates a reflection coefficient better than almost -20 dB for both polarization modes, an average transmission loss of 0.2–0.5 dB, and isolation and cross-polarization leakage levels exceeding 80 dB and 58 dB, respectively, across the entire band.**

Keywords—Orthomode transducer (OMT), turnstile junction, wide-band, ridged waveguide, dual polarization.

I. Introduction

Orthomode Transducers (OMTs) are critical receiver components that detect or separate out the polarization of incoming signals, and are widely used in applications like radio astronomy and communication systems. In communication systems, efficient spectrum reuse is supported to maximize capacity and performance [1]. OMTs are used in antenna feed systems across various electromagnetic wavelengths, including microwave and mm-wave to sub-millimetre wavelengths. Various symmetric and asymmetric OMT configurations are suggested for several applications. Asymmetric OMTs like fin-line [2] are ideal candidates for applications with narrow bandwidths, with the drawback of poor overall polarization isolation due to the presence of higher-order modes [3]. In mm-wave applications, which require critical considerations like precision manufacturing, suppression of higher-order modes, and broader bandwidths, symmetric structures are generally preferred for OMT designs like Boifot [1], [4] and turnstile junction OMTs. Such designs are recognized for their wide bandwidth and applications in higher frequency ranges due to folded symmetric structures and direct connectivity to antenna feed sources, eliminating the need for square-to-circular waveguide transitions. However, turnstile OMTs are favored over Boifot ones due to their two-fold turnstile symmetry, which results in improved isolation and eliminates the need for septa and pins for impedance matching [5].

In response to the increasing demands of advanced terahertz receivers used in radio telescopes, this section reviews OMTs designed for mm-wave frequency ranges. They are usually preferred to wire-grid polarizers because of their compact structure. In ref. [6] an OMT for the 200-270 GHz band is designed for the CARMA array with a circular waveguide input and two WR 3.7 outputs. Simulations predicted a reflection coefficient below -20 dB, cross-polarization and isolation of ~25 dB, and transmission loss of ~0.6 dB at room temperature, improving to ~0.2 dB at 4 K. The OMTs were produced in a four-block configuration using various metals and machining methods. The OMT in [7] is the first silicon-micromachined turnstile OMT for the 220–330 GHz range, achieving 0.3 dB average insertion loss, 60 dB cross-polarization, and 22 dB average return loss. The paper addresses fabrication challenges at millimetre-wave frequencies and uses a three-chip silicon-on-insulator stack. In ref. [8] a compact W-band (75–110 GHz) OMT using a “swan neck” twist for the connection between a turnstile junction and an E-plane Y-junction for minimizing the overall OMT structure is simulated and 3-D printed using a digital light processing (DLP) method. The vertical and horizontal ports have average return losses of 17 dB and 15 dB, insertion losses of 0.6 dB and 0.5 dB to the standard port, and an isolation of 28 dB. The high amount of isolation is attributed to the fabrication asymmetry of the turnstile junction. Simulation results are given in [9] for the design of a 180-260 GHz orthomode transducer with insertion loss below 0.05 dB; the return loss exceeds 20 dB, and the isolation between orthogonally polarized waves is around 55 dB. A WR10 turnstile OMT in ref [10] for the CLOVER experiment is introduced. It is a simple, cost-effective structure designed for characterizing the polarization of the cosmic microwave background (CMB). The OMT achieves high return loss 22 dB, low insertion loss 0.3 dB, and isolation about 45 dB. All the mentioned works have a frequency range of less than an octave bandwidth.

A long-term goal in radio astronomy applications is to increase the bandwidth of low noise receivers. To address this, refs [11], [12] have implemented ridged turnstile junctions and waveguides in the frequency range of the K, Ka, and part of the V band to achieve octave bandwidth OMTs. To extend the bandwidth of the turnstile OMT originally designed in [12] to

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approximately 2.5:1, covering the frequency range of 65–165 GHz, the proposed model has been redesigned and simulated. The performance of the OMT has been validated through simulations using two full-wave electromagnetic tools: HFSS and CST Studio Suite.

II. Design and Optimization

A. *Quad-Ridge Waveguide Turnstile Junction*

The 3-D view and the inner ridge details and optimized results of the proposed turnstile junction are shown in Fig. 1. Its architecture has three major parts: a single quad-ridge circular waveguide, two cylindrical-shaped matching stubs and four single-ridged rectangular waveguides. In the turnstile junction, equal splitting and recombination of the signal is important to avoid trapped modes; therefore, path lengths must be equal. The input signal from the standard port is split in two ways by the matching stub, facilitating high isolation between the output ports. The connections between ridged waveguides and matching stubs are important to achieving the desired reflection coefficient. Therefore, the gap between the ridged waveguides and the matching stub is optimized. Higher order modes excited inside the turnstile junction are controlled by the lengths of steps, the matching stub, and the ridged waveguide.

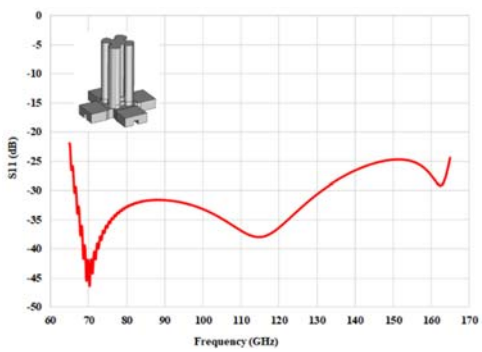
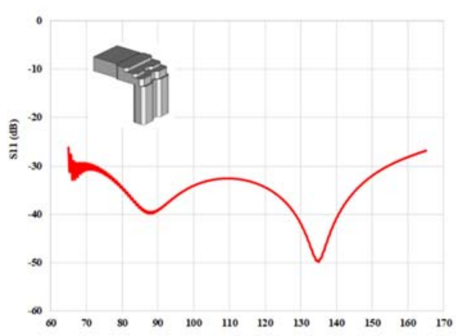


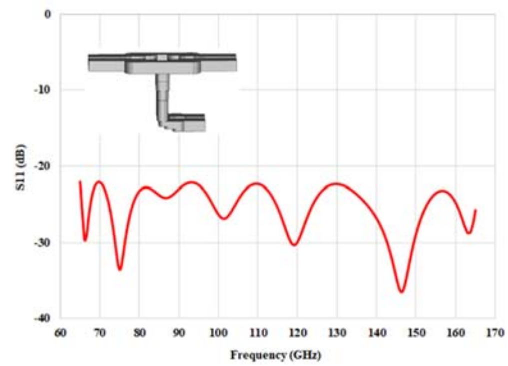
Fig. 1. CAD view and simulated reflection coefficient for the quad-ridge waveguide turnstile junction.

B. *E-Plane Bend and Y-Junction with Ridged Waveguides*

Fig. 2 (a) and (b) illustrate the design details and simulation results of the E-plane bend and T-junction connected to the E-plane bend ridged waveguides, respectively. The symmetry of recombined branches using T-junctions is important to minimize spikes in the receiver in the overall system. It can be seen that the return loss of both the bend and the T-junction exceed 25 and 22 dB across the entire operating bandwidth.



(a)



(b)

Fig. 2. (a) CAD model of the bend and (b) E-plane Y-junction connected to E-plane bend, simulated input port reflection.

C. *Design Overview of OMT*

Fig. 3 illustrates the designed OMT structure based on the key components detailed in previous sections. In the layout of the OMT, maintaining alignment, symmetry, and proper spacing is crucial for achieving a clean and optimal signal response [13].

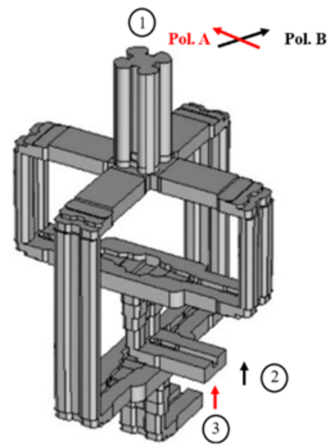


Fig. 3. Layout of quad-ridge turnstile OMT design modeled in CST and HFSS.

Fig. 4 shows a comparison of input reflected port power using HFSS and CST. The simulations demonstrate that the reflection coefficients of the designed OMT are mostly better than -20 dB across the whole 65–165 GHz range in both software applications.

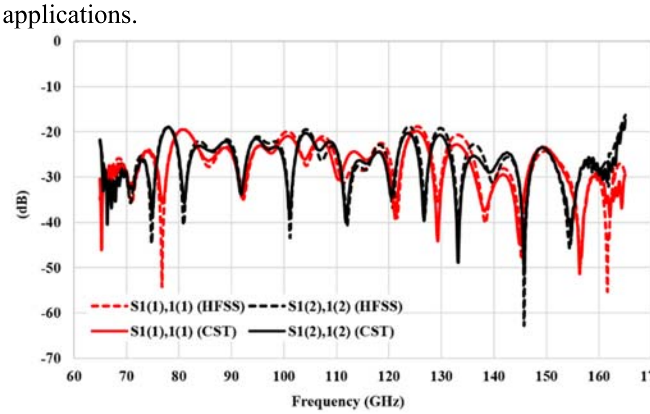


Fig. 4. Simulated Pol 1 and Pol 2 reflected power of the OMT in CST and HFSS.

Additionally, horizontally and vertically polarized waves show simulated transmission losses to almost less than 0.5 dB through their horizontal and vertical polarization paths, considering the surface conductivity of 3.56 × 107 S/m used for simulation (Fig. 5).

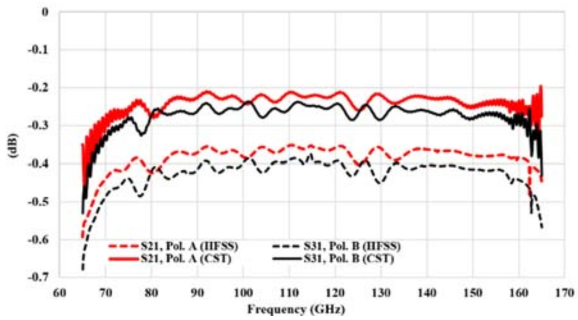


Fig. 5. Simulated Pol 1 and Pol 2 insertion loss across the band in CST and HFSS.

Fig. 6 shows that cross-polarization leakage is less than -58 dB, demonstrating minimal trapped energy within the structure and very low modal conversion (reflected higher-order modes are less than -50 dB). The simulation results for port isolation remains below -80 dB throughout this frequency range.

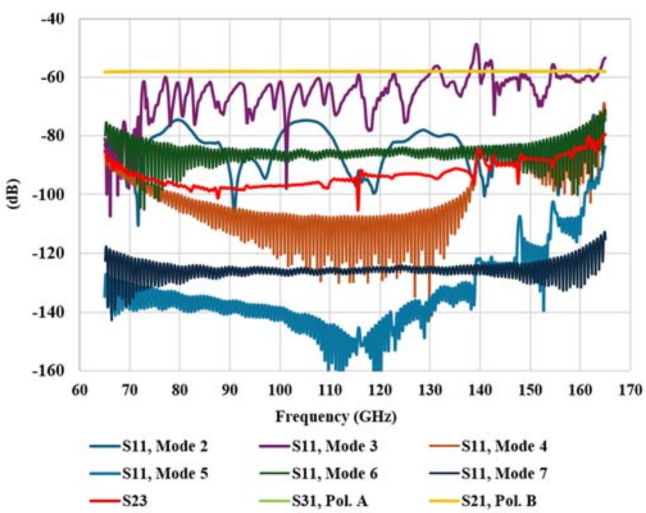
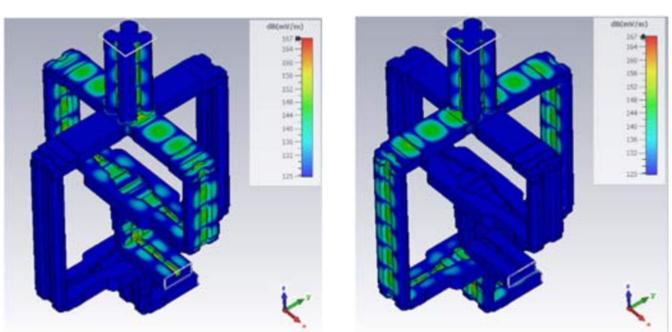


Fig. 6. Simulated Pol 1 and Pol 2 return loss of the OMT in CST.

Fig. 7 illustrates the simulation results of the electric field distribution in the proposed OMT for each linear polarization.



(a) (b)

Fig. 7. Simulated electric field distribution; (a) horizontally polarized wave propagating through port 3, (b) vertically polarized wave propagating through port 2.

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