Waveguide Components for wSMA Frontends

Lingzhen Zeng[1], C. Edward Tong[1], and Paul K. Grimes[1]

***Abstract*—We report on the development of the next generation of wideband Submillimeter Array (wSMA) low band and high band frontend waveguide components: from the design, fabrication, to the measurement of the prototypes. We also report on the ongoing effort of the integration of these frontend components into a receiver cartridge.**

***Index Terms*—Directional couplers, frontend, orthomode transducers, waveguide twists**

I. INTRODUCTION

THE Submillimeter Array (SMA) is an eight antenna interferometer array on the summit of Mauna Kea, Hawaii. The array is undergoing a major upgrade to become the wideband Submillimeter Array (wSMA). The wSMA upgrade will include a new cryostat with two receiver cartridges for each antenna: the low band receiver will be operated by a local oscillator (LO) tunable between 210 GHz and 270 GHz; while the LO for the high band receiver will be tunable between 280 GHz to 360 GHz. Each receiver will offer a wideband intermediate frequency (IF) of 4 GHz to 20 GHz [1].

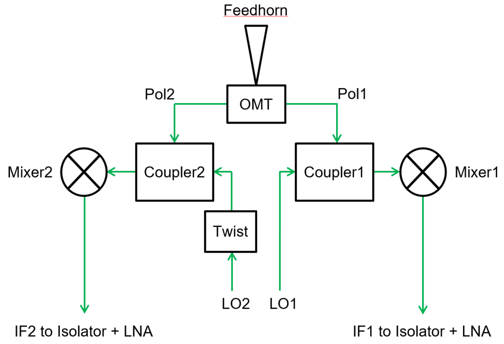

Fig. 1 Schematic diagram of wSMA frontends

As shown in figure 1, the frontend of each wSMA receiver consists of a number of waveguide components, including a profiled-corrugated feedhorn, a Bøifot type orthomode transducer (OMT), two silicon-chip-based LO couplers and a rectilinear waveguide twist. The LO couplers couple the LO signal in to the sky signal coming from the OMT outputs. The waveguide twist rotates the E-plane of the LO2 port for compact integration. The OMT, couplers and waveguide twist are integrated into a single block. The LO signal is injected from the bottom of the block through standard UG-387 waveguide flanges. Two mixer blocks, each equipped with a readout box, are mounted to the sides of the frontend assembly through custom design waveguide flanges. The IF readout circuits are integrated in the readout boxes. Because of the wideband specifications of the wSMA receivers, we have designed all these waveguide components to operate over a 40% fractional bandwidth.

II. ORTHOMODE TRANSDUCER

An OMT is a passive device that separates an input signal into two orthogonal linearly polarized components. The double-ridge Bøifot type OMT design [2], [3] has been well studied for operating at millimeter and submillimeter wavebands. The wSMA OMT follows a similar design to that shown in [3]. The OMT junction, geometry of the side waveguides, the combiner, and the transformer design for the vertical waveguide were further optimized.

The HFSS model and photos of our WR4.3 OMT prototypes are shown in figure 2. The design is more compact than the previous designs in [2] and [3]. Our prototypes consist of four machined parts. To avoid the need to fabricate a deep hole for the vertical polarization port waveguide (P2), we replaced a long section of P2 by a straight split-block waveguide.

Fig. 2 CAD model and photos of our WR4.3 OMT prototype

We measured our OMT prototypes using a back-to-back configuration. We mated the input square waveguide ports of two OMTs and measured the S-parameters through the ports P1 and P2. This configuration gave us the worst-case scenario performance of the prototypes. Referring to figure 3, excellent performance over a full waveguide bandwidth was obtained. The total insertion loss of the two back-to-back OMTs is better than 1 dB across most of the band. Given the insertion waveguide length of each OMT is 30 mm, the intrinsic insertion loss of the OMT is very low. The measured polarization isolation is around 50 dB and the return losses of the rectangular waveguide ports are around -20 dB for both polarizations.

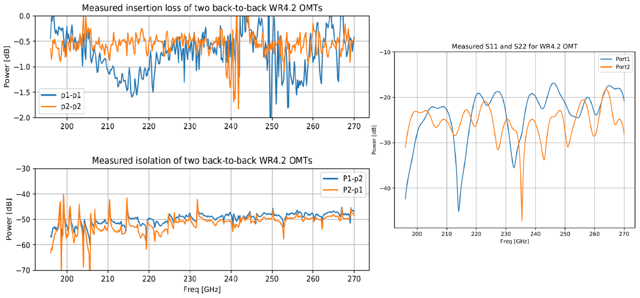

Fig. 3 Measured insertion loss, isolation and return loss from a back-to-back configuration of our WR4.3 OMT prototypes

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III. LO WAVEGUIDE COUPLER

Chip-based directional couplers using three sets of probes connected by suspended striplines (bow-tie antennas) were proposed in [4], [5]. The original designs used three bow-tie antennas fabricated on individual quartz substrates. However, given the small chip sizes needed for operation at these wavelengths, it is difficult to install and align each individual in place, and this led to significant differences between the measurement and simulation data [5].

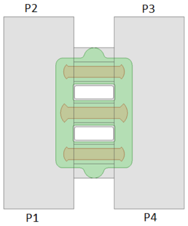

Fig. 4 schematic of waveguide chip coupler

Figure 4 shows the wSMA chip coupler design. Three bow-tie antennas were integrated on a single silicon chip, with two open slots in the center. This design allows easy and reliable chip installation. Our coupler prototype for WR4.0 band is shown in figure 5. Our measurement results agree very well with the simulations. As shown in figure 6, we achieved a flat coupling curved across a wide operation bandwidth. A paper showing the details of this coupler design is submitted to IEEE Transactions on Terahertz Science and Technology [6].

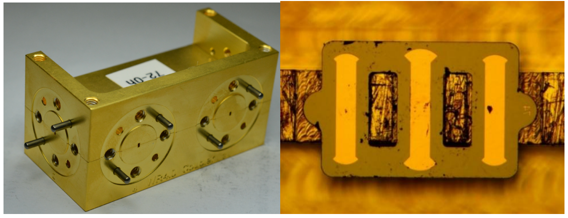

Fig. 5 Prototype of WR4.0 waveguide chip coupler

Fig. 6 measurement results of WR4.0 chip coupler

IV. WAVEGUIDE TWIST

The function of a waveguide twist is to rotate the polarization plane of the electromagnetic wave propagating inside a waveguide system by a specified angle. In the wSMA frontend design, the waveguide twist rotates the orientation of one of the LO ports, allowing proper waveguide bending from the bottom of the receiver cartridge.

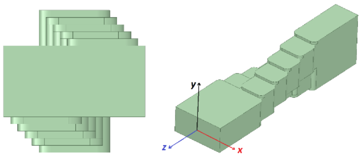

Fig. 7 CAD model of wSMA waveguide twist design

Our waveguide twist is a novel rectilinear design [7], which covers a full waveguide bandwidth. As shown in figure 7, the design achieves compactness and ease of fabrication by utilizing a series of quarter-wave transformer steps machined in split blocks. Figure 8 shows the prototypes of our WR3.4 waveguide twist. The top and bottom blocks are designed to be identical to reduce the fabrication costs. The measured S-parameters are shown in figure 9. The return losses are better than -25 dB and the insertion loss is about 0.6 dB across the entire waveguide band. This data includes a 12-mm long waveguide section from either side of the waveguide ports, leading to the actual twist itself. As a result, we believe that the actual performance of the twist should be even better.

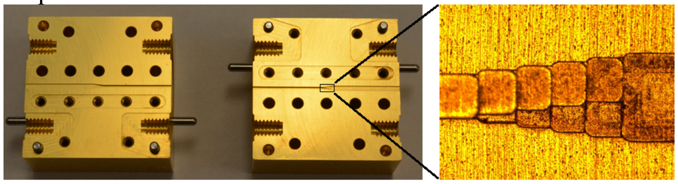

Fig. 8 Prototypes of wSMA waveguide twist

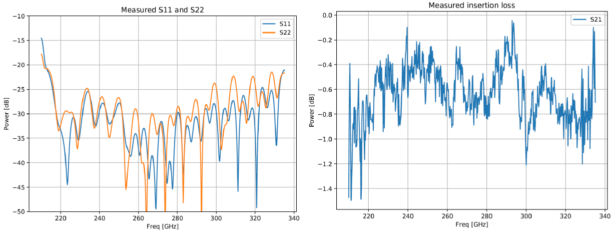

Fig. 9 Measurement results of wSMA waveguide twist

V. FRONTEND INTEGRATION

Using the components described in the above sections, we have designed an integrated frontend assembly, and Figure 10 gives the CAD model. It consists of an OMT, two couplers and one waveguide twist. The RF signal enters from the square input waveguide port. The LO signals are injected from the bottom of the assembly through standard UG-387 waveguide flanges.

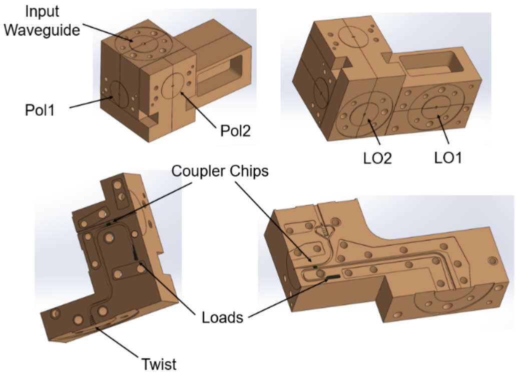

Fig. 10 CAD model of wSMA frontend assembly

As shown in figure 11, the frontend assembly will be integrated with a feedhorn and mixer blocks. The feedhorn is mounted on the top and the two mixer blocks and their associated readout boxes are mounted to the sides of the assembly through custom-designed waveguide flanges.

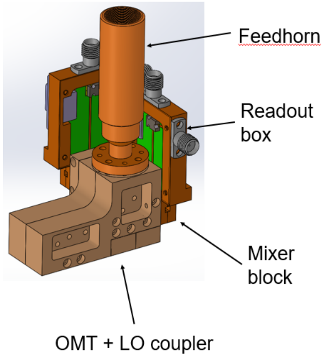

Fig. 11 CAD model of wSMA frontend assembly with feedhorn, mixer blocks and readout box

VI. CONCLUSION

A number of waveguide components have been developed for the wSMA frontend. The measurement results of the prototypes agree well with simulations and meet the requirements of the project. Further work frontend integration and system performance tests will follow.

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