Design and Characterization of 3D Printed Polymer Terahertz Multi-Mode Interference Couplers

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***Abstract*—In this paper, we present the design of one-dimensional symmetric and paired 1 × 2 multi-mode interference (MMI) couplers at 140 GHz applying a modal propagation analysis together with electromagnetic simulation. The designed couplers are fabricated by 3D printing and are characterized by terahertz frequency-domain spectroscopy. The measured amplitude imbalances between the outputs of the couplers are as good as 0.32 dB.**

I. INTRODUCTION

With the growing potential of terahertz applications over the last few years, associated terahertz devices have been intensively developed [1], [2]. Especially 3D printed dielectric devices attract a great interest in the research community [3]. The 3D printing technology is well-suited for the fabrication of dielectric waveguides [4], [5]. Waveguide integrated couplers as components for power combining or power division play an important role for future terahertz systems. Multi-mode interference (MMI) couplers are more promising compared to other types of couplers because they allow an arbitrary number of inputs and outputs and offer 0°, 90°, or 180° phase shifts between the outputs. While the design of MMI couplers is relatively simple, the traditional fabrication by a conventional subtractive technology is rather complicated, expensive, and time-consuming. Therefore, 3D printing has drawn great attention due to its technological feasibility and cost-effectiveness. In this paper, we present 3D printed symmetric and paired MMI couplers with a high-impact polystyrene (HIPS) core and air cladding at 140 GHz.

II. DESIGN OF MMI COUPLERS

Symmetric and paired one-dimensional 1 × 2 MMI couplers made of HIPS for 140 GHz are designed in this work. The phase differences between the outputs are 0° and 90°, respectively. In previous work, we have characterized dielectric waveguides with a core of square cross-section 1.1 mm × 1.1 mm made of HIPS for single-mode operation at 140 GHz [6]. We chose the height of the MMI region the same as the height of the input and output waveguides, so that this dimension supports only single-mode propagation. The lateral dimensions of the symmetric and paired couplers are shown in Fig. 1. These dimensions are determined by applying the modal propagation analysis of multi-mode interference [7] and optimized by performing electromagnetic full-field simulations using the finite-difference time-domain solver Empire XPU.

III. MEASUREMENT SETUP AND RESULTS

The couplers are characterized by determining their amplitude and phase balances using the frequency-domain spectroscopy system Toptica TeraScan 1550. The system enables both amplitude and phase measurements. As shown in Fig. 2, the terahertz beam is focused by two Polytetrafluoroethylene (PTFE) lenses into the input waveguide

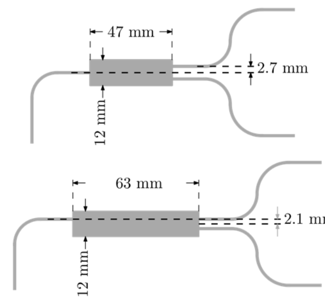

Fig. 1. Lateral dimensions of the (a) symmetric coupler and (b) paired coupler.

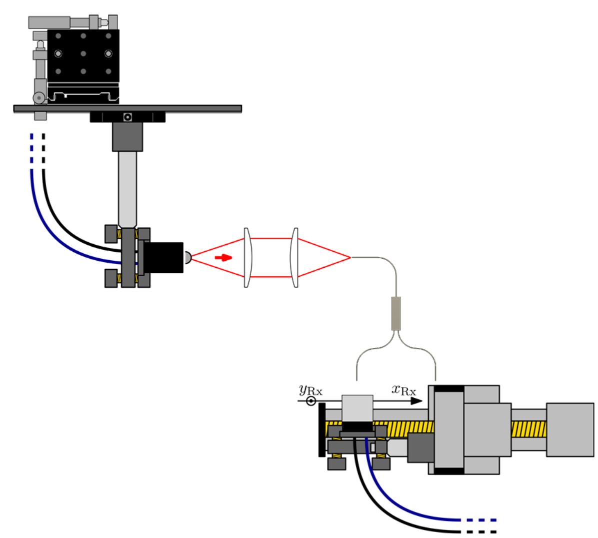

Fig. 2. Measurement setup of the transversal scan

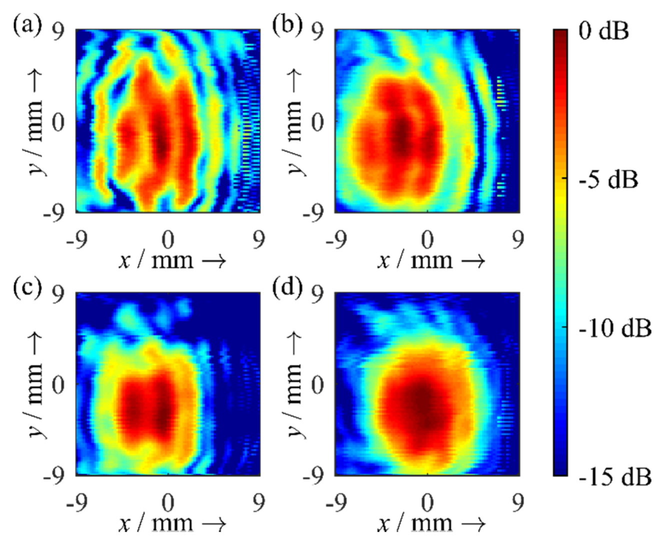

Fig. 3. Transversal scan of the far field radiation patterns at the outputs of the (a,b) symmetric coupler and (c,d) paired coupler.

of our MMI coupler which is clamped between two low density polystyrene foam blocks and fixed on a rotation stage for precise alignment. The transversal scan of the far-field radiation patterns and the phase distributions at the two outputs of the coupler are measured by moving the detector with a motorized two-axis translation stage. For the phase balance determination, it is crucial that the distances between the detector and the two outputs of the coupler are identical. For the adjustment before the measurement, we manually rotate the rotation stage on which the coupler under test is fixed, measure the distances between the terahertz detector and the two outputs of the coupler with feeler gauges, and repeat these two steps until the distance difference is below 40 µm. The far field radiation patterns at the two outputs of the symmetric and paired coupler are shown in Fig. 2 (a,b) and Fig. 2 (c,d), respectively. The amplitude balance is determined by summing up the detected photocurrent over the planar scanning area. The total detected photocurrents at the two outputs of the symmetric coupler are 86.61 dBnA and 87.8 dBnA, which results in a 1.19 dB amplitude imbalance. For the paired coupler, the total detected photocurrents at the two outputs are 90.02 dBnA and 90.34 dBnA, which results in the amplitude imbalance of 0.32 dB. The phase shifts between the outputs of the symmetric and paired couplers are 20.53° and 114.08°, respectively. The phase error is less than 25°, which is adequate considering the following. First, the achievable dimensional accuracy of the 3D printer is on the order of hundreds of micrometers. Second, the 40 µm distance uncertainty between the terahertz detector and the outputs of the coupler alone can lead to a phase error of 6.7°. Moreover, the inhomogeneity of the low density polystyrene foam, which is the cladding of the multi-mode section of the coupler, can vary the multi-mode interference pattern from the theoretical one.

Conclusion

In this work, we have designed, 3D printed, and measured symmetric and paired MMI couplers working at 140 GHz. The results from the transversal scan measurements indicate quite indistinguishable power splitting performance of these two different types of 3 dB couplers with amplitude imbalances less than 1.19 dB. Furthermore, we have successfully verified the 0° and 90° phase shifts between the outputs of the symmetric and paired couplers, respectively.

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