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# A planar 925-GHz branch line coupler

Aditya Goturu, Malte Dornieden, and Jan Stake

Terahertz and Millimetre wave Laboratory, Department of Microtechnology and Nanoscience (MC2)  
Chalmers University of Technology, SE-412 96 Göteborg, Sweden

**Abstract**—Waveguide couplers become increasingly difficult to fabricate at higher terahertz frequencies. In this work, we present a planar branch line coupler with a centre frequency of 925 GHz. The circuit is realized in suspended stripline technology, using a 3- $\mu\text{m}$  silicon-on-insulator membrane. The coupler, embedded via probe transitions in a waveguide system, shows a simulated bandwidth of 18% with return loss and isolation better than 15 dB. The amplitude balance is better than 0.4 dB across this band.

## I. INTRODUCTION

THz instruments have to work with extremely low power levels, both from the signals they receive as well as from locally generated sources. Power splitting and combining circuits will be a key component [1] in future THz instruments for radio astronomy and Earth science, enabling advanced mixer topologies, such as sideband-separating mixers [2], or power-combined sources. However, the implementation of THz couplers remains relatively unexplored.

At THz frequencies, couplers have almost exclusively been implemented in the rectangular waveguide [3], as multi-section branch line couplers [4] in E-plane split blocks. These couplers need slots with high aspect ratios, which become increasingly difficult to machine at higher frequencies. The use of lithographic micro-fabrication techniques can allow for higher aspect ratios [5], but these designs remain extremely sensitive to misalignment during assembly.

In this work, we present a coupler designed in a suspended-stripline membrane-circuit technology, similar to most mixers operating at these frequencies [6]. Such a coupler can be fabricated by lithographic patterning along with one of metal layers of a mixer. The suspended-stripline channel is inherently tolerant to misalignment during assembly, and would also reduce the machining complexity of highly-integrated mixer blocks.

## II. METHOD

To demonstrate the potential of planar couplers, we chose to implement a classical branch line coupler [7] for the WM-250 [8] band (750-1100 GHz).

TABLE I: Design parameters

Parameter	Value
Waveguide (WM-250)	250 $\mu\text{m}$ x 125 $\mu\text{m}$
Stripline channel base	70 $\mu\text{m}$ x 30 $\mu\text{m}$
Stripline channel cap	90 $\mu\text{m}$ x 30 $\mu\text{m}$
Stripline channel substrate width	55 $\mu\text{m}$
Conductor thickness	0.3 $\mu\text{m}$
Substrate thickness	3 $\mu\text{m}$
Chip size	415 $\mu\text{m}$ x 415 $\mu\text{m}$
Feed and branch conductor width	10 $\mu\text{m}$
Through conductor width	24 $\mu\text{m}$

The coupler uses a branch line with the same impedance as the feed ( $Z_0$ ), and a through line with an impedance of  $\sqrt{2}Z_0$ . A stripline conductor width of 10  $\mu\text{m}$  was chosen as the feed line, with an impedance  $Z_0 \approx 120 \Omega$ , and the width for the through line was found to be around 22  $\mu\text{m}$ . As the side-wall distances and effective substrate widths for the branched and through lines are not

identical to the feed line, the widths of the branch and through lines were tuned. Additionally, the quarter-wavelengths vary slightly due to small changes in the effective dielectric constants, therefore the lengths of lines were tuned in the final model. All structures were modeled and optimized in a 3D finite-element electromagnetics (3D EM) solver. Post optimization, the final through line width was found to be around 24  $\mu\text{m}$ .

Fig. 2: 3D model of the E-plane split block

As the coupler cannot be directly characterized in a suspended stripline system, appropriate transitions [9] were designed from the WM-250 waveguide. The transitions were separately modeled and optimized before being combined with the coupler. The 3D EM simulation of the transitions alone showed a return loss better than 20 dB and insertion loss better than 0.4 dB through the entire band. Four transitions were then attached to the coupler model and the entire device was simulated with realistic metal losses.

Continuous beam-leads along the stripline create a significant junction effect when branching. To avoid this, the coupler was designed without beam-leads, and it is assumed that the surrounding

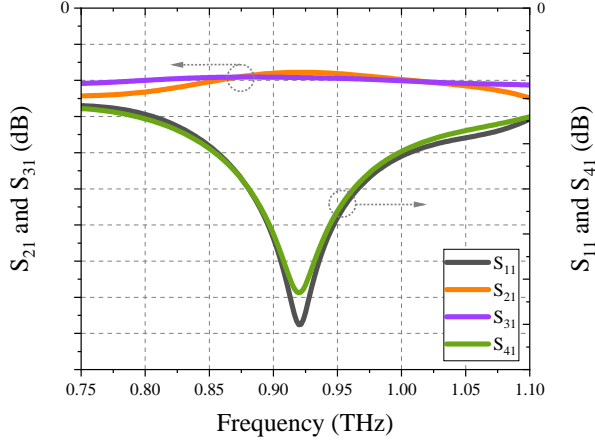


Fig. 3: S-parameters estimated from 3D EM simulation (reference planes indicated in Figure 1).

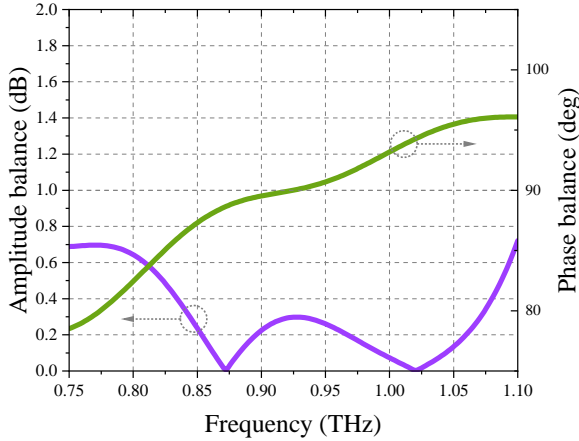


Fig. 4: Amplitude and phase balance estimated from 3D EM simulation (reference planes indicated in Figure 1).

circuitry (in this case the waveguide transitions) would provide the necessary mechanical supports. The couplers are fabricated by patterning the front side of a silicon-on-insulator (SOI) material, followed by thinning and backside patterning of the membrane on the 3- $\mu\text{m}$ -thick device layer. The membrane is then suspended on its beam-leads in an E-plane split block with access waveguides (Fig. 5).

### III. RESULTS

The 3D EM simulation of the coupler (Fig. 3 and 4, reference planes indicated in Fig. 1) showed a return loss better than 15 dB for 18% bandwidth at a centre frequency near 925 GHz. The amplitude balance is better than 0.4 dB across this band, and the phase balance is  $\pm 5^\circ$ . The peak directivity is estimated to around 27 dB. The coupler itself has an efficiency factor greater than 90% across the entire band.

### IV. CONCLUSION

We have demonstrated the theoretical potential of planar suspended stripline couplers.

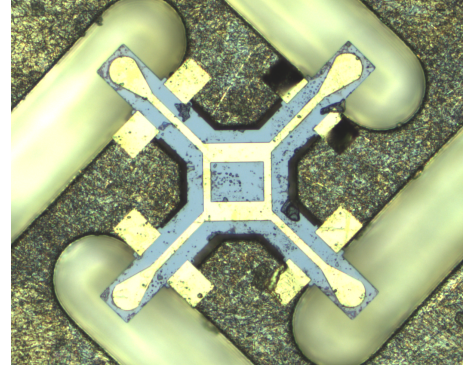


Fig. 5: The fabricated coupler membrane mounted in the base block.

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