THz Waveguide Couplers Using Quartz Micromachining

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***Abstract*— A series of waveguide couplers using a novel configuration have been designed and measured from WR-5.1 (140-220 GHz) to WR-1.5 (500-750 GHz). The coupling is achieved using a microstrip quarter-wave coupled line, allowing for coupling factors from 7 dB to 11 dB and directivity of better than 20 dB. The coupling circuits consist of a quartz circuit micromachined into an "H" shape to transition from microstrip to waveguide. Measurement of the couplers showed good agreement between the simulations and experiment. The measured insertion loss ranges from 2 dB at WR-5.1 to 5 dB at WR-1.5.**

I. Introduction

Waveguide directional couplers are an essential piece of test equipment at microwave and mm-wave frequencies, and a variety of coupler designs are available up to about WR-10 (75-110 GHz). Above WR-10 there are fewer options, in part because scaling designs to the THz region can be challenging. Several groups have reported coupler designs extending into the THz region, using either traditional machining or lithographic micro-machining techniques [1]–[4]. The fabrication of these THz couplers is quite challenging, which has tended to limit the widespread use of these elements.

This article describes a novel waveguide coupler that uses a microstrip quarter-wave coupled line coupler connected to waveguide using microstrip-to-waveguide probes. The design has low loss, wide bandwidth, flat coupling factor, compact size, and moderate directivity. Because of its compact size and the use of an E-plane split, the coupler can be integrated with other E-plane split components. The coupling factor is determined by the circuit design, with no change in the block design required. The basic design can be scaled to above 1 THz using conventional machining techniques.

II. Coupler Design and Fabrication

The coupling is accomplished using microstrip quarter-wave coupled lines, as shown in Fig. 1(a). Using this design, a flat coupling factor can be achieved over a full waveguide bandwidth. In order to couple the microstrip into waveguide, the lines are bent and separated into 4 separate microstrip channels, as shown in Fig. 1(b). Microstrip loss at THz is significantly higher than waveguide loss, and so it is desired to launch into waveguide as soon as possible. The microstrip is transitioned to waveguide using a conventional E-plane waveguide-to-microstrip probe. The bends and transitions were found to have little effect on the performance of the coupler, which is shown in Fig. 1(c). The coupling is flat to within 0.5 dB over the full waveguide band, and the directivity is predicted to be 20 dB or better.

The coupler circuit needs to be H-shaped, and so it cannot be diced using a standard dicing-saw. To form the circuits into the correct shape, an ICP-RIE micromachining process was used to etch the quartz. Fig. 2(a) and 2(b) show close-ups of the circuits during and after the fabrication process. This circuit is then mounted into an E-plane split machined block, and is then ready for testing, as shown in Fig. 2(c).

III. Measurement of a WR-2.2 Coupler

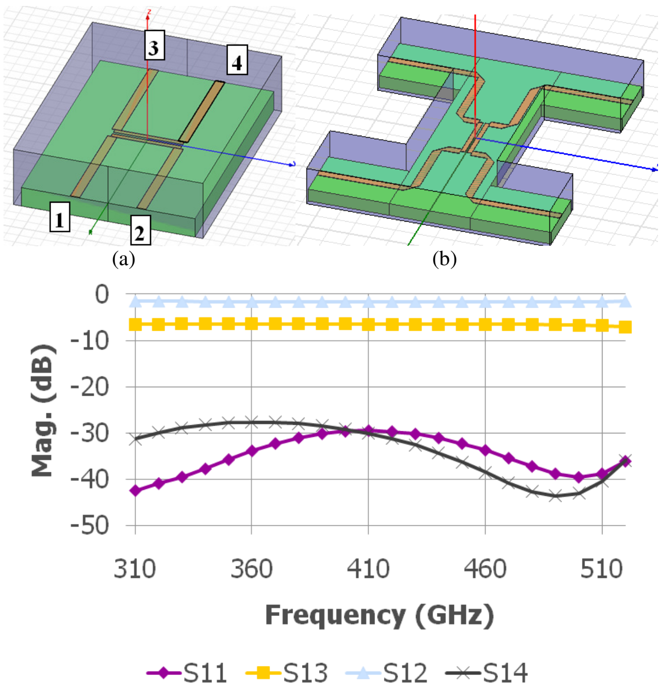
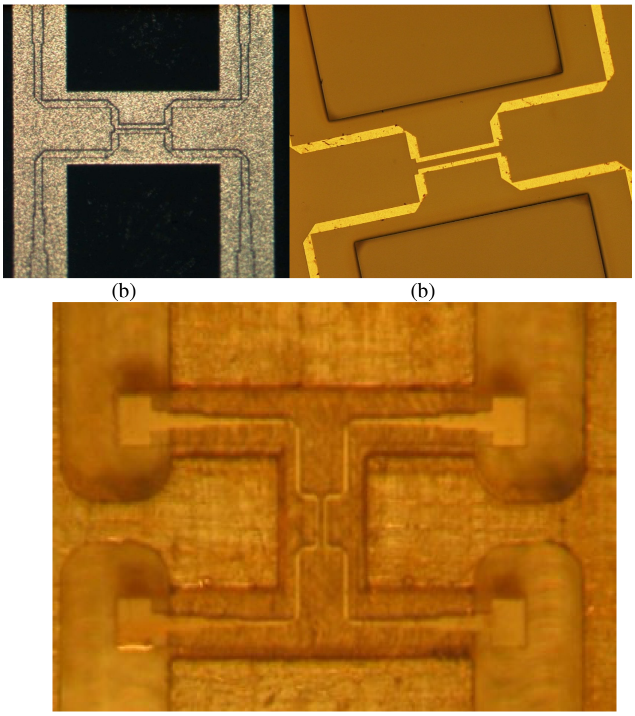


Fig. 1. (a) Schematic of the microstrip quarter-wave coupled line, (b) Schematic showing the separation of the 4 microstrip lines into separate channels, and (c) HFSS simulation of the coupler performance.



(c)

Fig. 2. (a) Photograph of the circuit during fabrication, with the metal etch mask still on the circuit, (b) the coupler section of a completed H-circuit, and (c) the H-circuit mounted into an E-plane split block.

Initial testing of the couplers has been performed using a THz source and a calorimeter, using a substitution method to normalize the source & calorimeter responses. The measured performance of a WR-2.2 coupler (330-500 GHz) is shown in Fig. 3. The WR-2.2 coupler was an early prototype, and had excess waveguide length, and thus its insertion loss was about 4 dB. Reducing the length is predicted to allow a reduction in insertion loss to less than 3 dB. A WR-3.4 (220-330 GHz) coupler was designed that has a more optimum waveguide length, and for a coupling factor of 8.5 dB the insertion loss was 2.5 dB, consisting of 1 dB of waveguide/circuit loss and 1.5 dB of input power coupled to Port 3. The length of waveguide inside the block is ~23 mm, and assuming a waveguide loss of .025 dB/mm yields a conductor loss of 0.6 dB, leaving 0.4 dB loss for the coupler itself.

Measurements of the directivity were difficult given the limited dynamic range of the test system, but indicated a value in the range 20 dB where sufficient test power was available. Additional testing using a heterodyne VNA extender system is underway, and is expected to allow full measurement of the coupler directivity even for the highest frequency coupler.

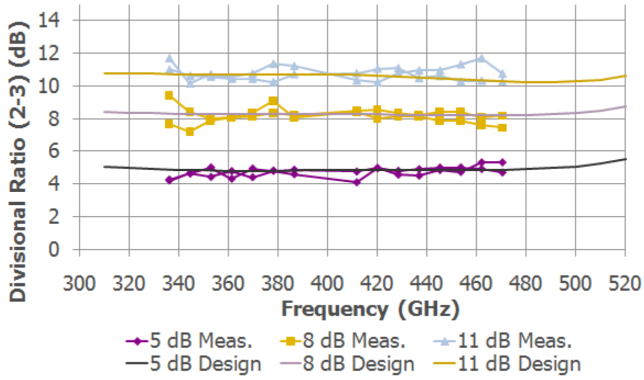


Fig. 3. Measured performance for six WR-2.2 (330-500 GHz) couplers, two each of 5 dB, 8 dB, and 11 dB designs. The divisional ratio is the ratio of power measured at Port 2 and Port 3 of the coupler when power is input into Port 1. The coupling factor is equal to the divisional ratio plus the coupler insertion loss.

IV. Conclusions

A series of manufacturable THz waveguide couplers have been designed, and have exhibited very flat coupling factor and low insertion loss over a full waveguide band. These couplers are now being used routinely for measurements at VDI.

Regarding future work, the directivity of these couplers can possibly be improved by using a “wiggly-line” coupler [5] to help balance the even and odd mode phase velocities. Also, there are a wide variety of microstrip couplers, splitter, and hybrid designs that can be placed in the same basic housing, and so this basic technology can have wide applications in THz test and measurement.

References

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