Integrated Microstrip and Rectangular Waveguide in Planar Form

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***Abstract*—Usually transitions from microstrip line to rectangular waveguide are made with three-dimensional (3-D) complex mounting structures. In this paper, a new planar platform is developed in which the microstrip line and rectangular waveguide are fully integrated on the same substrate, and they are interconnected via a simple taper. Our experiments at 28 GHz show that an effective bandwidth of 12% at 20 dB return loss is obtained with an in-band insertion loss better than 0.3 dB. The new transition allows a complete integration of waveguide components on substrate with MIC's and MMIC's.**

***Index Terms*—Integrated rectangular waveguide, microstrip to waveguide transition.**

I. Introduction

RECTANGULAR waveguide can be used to design high-Q components but requires complex transitions to integrated planar circuits. Several studies of transitions between microstrip line and rectangular waveguide have been reported [1]–[4]. However, typical integration schemes from rectangular waveguide with planar structure are bulky and usually require a precision machining process, which is difficult to achieve at millimeter-wave frequencies for mass production. The transitions always consist of two or more separate pieces that require judicious assembly, and a tuning mechanism is also generally essential. Furthermore, the planar substrate has to be cut into a specific shape. These constraints make integration difficult and costly.

A straightforward solution is to integrate the rectangular waveguide into the microstrip substrate. This will surely reduce the Q factor of the waveguide because of dielectric filling and volume reduction, but the entire circuit including planar circuit, transition and waveguide can be constructed using standard PCB or other planar processing techniques. In this letter, a new integrated platform of microstrip line and rectangular waveguide is presented, in which the two dissimilar structures are oriented in the same axis, thereby reducing the total size required for the transition. This transition structure makes use of a tapered microstrip line to excite the waveguide mode. The waveguide is synthesized on the substrate with linear arrays of metallized via holes in our experiments, but metallized grooves could also be used. Since all the components are designed on the same substrate, a planar fabrication technique can guarantee excellent mechanical tolerances as well as tuning-free design. This is in particular of interest for multilayered processes such as low-temperature co-fired ceramic (LTCC) platforms.

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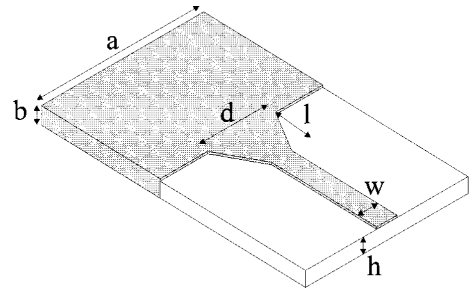

Fig. 1. Configuration of the proposed transition of microstrip line to rectangular waveguide on the same substrate.

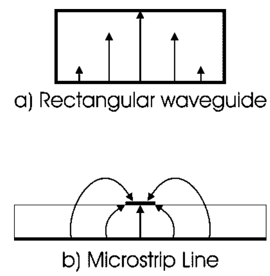

Fig. 2. Dominant modal electric field profiles (a) in rectangular waveguide and (b) in microstrip line.

II. Design of the Proposed Transition

Fig. 1 shows the proposed transition from microstrip line to rectangular waveguide within the same dielectric substrate. The structure consists of a tapered microstrip line section that connects a 50 Ω microstrip line and the integrated waveguide. The taper is used to transform the quasi-TEM mode of the microstrip line into the TE_{10} mode in the waveguide. As indicated in Fig. 2, the microstrip line is well suited to excite the waveguide because the electric fields of the two dissimilar structures are approximately oriented in the same direction and also they share the same profile. The design of such a transition is simple and straightforward. First, the size of the waveguide can be determined by considering the dielectric effect and well-established waveguide theory. The tapered section is then designed that interrelates the line width of the 50 Ω microstrip with the width of the integrated waveguide.

It is known that the propagation constant of the TE_{10} mode is only related to the width "a." Therefore, the height or thickness "b" of the waveguide can be reduced without much influence on the TE_{10} mode propagation, thus allowing its integration into

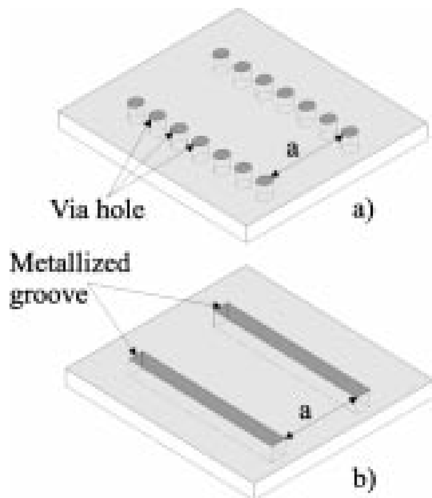

Fig. 3. On-substrate synthesized waveguide techniques: (a) metallized via-hole arrays and (b) metallized grooves.

a thin substrate that could reduce the radiation loss of the microstrip line. Nevertheless, reducing the height "b" will increase the conductor loss in both the microstrip line and rectangular waveguide. At millimeter-wave frequencies, the waveguide section is usually small and the conductor loss can be controlled at relatively low level. The sidewalls of the rectangular waveguide can be realized within the substrate by using a metallized post technique (arrays of vias) or a metallized groove technique, both illustrated in Fig. 3. In the H-plane, the ground plane of the microstrip line becomes one metallic wall for the waveguide while the tapered microstrip section provides the other metallic wall. This arrangement completes the waveguide structure. This scheme allows the design of very compact waveguide components with low loss such as T-junctions and filters.

A linearly tapered microstrip is used, and this smooth transition ensures a field matching between microstrip and rectangular waveguide over a broad bandwidth. The length "l" and width "d" of the taper, referring to Fig. 1, should be modeled and optimized over the desired frequency bandwidth. In our work, a commercial finite element method (FEM) package is used to carry out the transition design [5].

III. Experimental Results

To verify the proposed concept, a transition working in the LMDS frequency range is designed and measured. The whole structure consists of two back-to-back transitions separated by an integrated waveguide with a length of 16 mm. The circuit is constructed on a 0.254 mm thick dielectric substrate with $\varepsilon_r = 2.33$. The dimensions referring to Fig. 1 are selected as follows: $w = 0.711$ mm, $h = 0.254$ mm, $d = 2.286$ mm, $l = 5.588$ mm and $a = 6.096$ mm. This leads to a 50 Ω microstrip line and a waveguide operating from 19 to 32 GHz. The two electrical walls in the E-plane are constructed with 0.762 mm via-hole arrays. The spacing between two adjacent vias is also 0.762 mm. An HP8510 network analyzer and a Wiltron test fixture are used to measure the circuit with a TRL calibration.

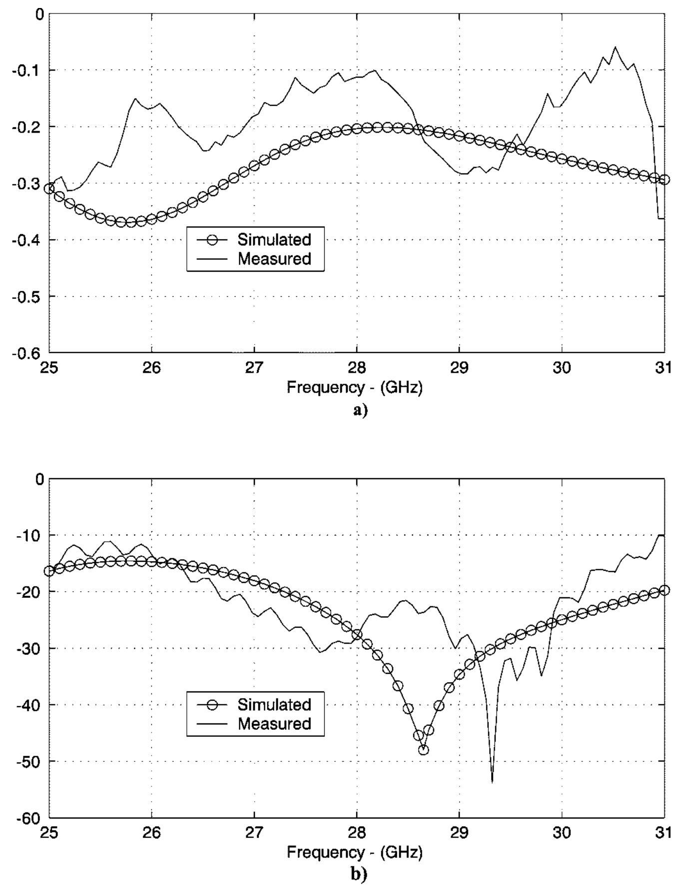

Fig. 4. Measured and simulated results for two back-to-back transitions with 16.0 mm integrated waveguide section. Design parameters are $w = 0.711$ mm, $h = 0.254$ mm, $d = 2.286$ mm, $l = 5.588$ mm, $a = 6.096$ mm. (a) Insertion loss. (b) Return loss.

Fig. 4 shows our simulated and measured results, which involve 1.524 mm microstrip line section (0.762 mm before each transition), the two transitions and 16 mm synthesized rectangular waveguide. A bandwidth of more than 12% is obtained here for 20 dB return loss from 26.65 to 30.20 GHz. The measured insertion loss is better than 0.3 dB in the entire band. We can see that the measured insertion loss is sometimes better than the simulated one. This may be explained by the fact that the substrate loss tangent at 10 GHz given by the manufacturer is used in the simulation. The value around 28 GHz should be lower.

IV. Conclusion

A new planar platform integrating microstrip line and rectangular waveguide has been presented, which involves a new transition between the two dissimilar structures. It allows the design of a completely integrated planar circuit of microstrip and waveguide on the same substrate without any mechanical assembly or tuning. Measured results agree well with the simulated ones for our fabricated sample of the transition. With its direct integration, small size and low loss, this new scheme is well suited for circuit design at millimeter-wave frequencies. It can be used to integrate passive waveguide components with MIC and MMIC active circuits.

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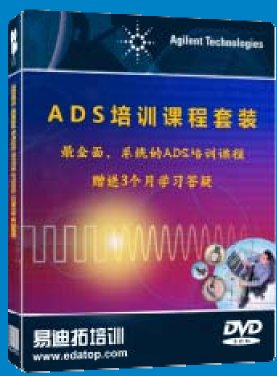

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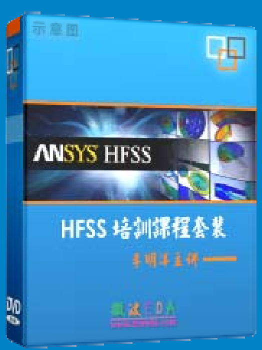

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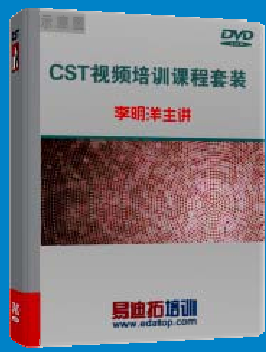

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