A Wideband Transition from Substrate Integrated Waveguide to Differential Microstrip Lines in Multilayer Substrates

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***Abstract* — In this paper, a novel transition from substrate integrated waveguide (SIW) to differential microstrip lines is presented and discussed. The transition can be used in multilayer environments such as multilayered thin film or low temperature co-fired ceramics (LTCC).**

***Index Terms* — Microstrip line, differential signal, substrate integrated waveguide (SIW), multilayer structure, transition.**

I. Introduction

In the last years, millimeter-wave applications both in the sensor (e.g. automotive radar) as well as in the communication area (e.g. point-to-point communication) have gained increasing interest. For a widespread commercial application, cheap MMICs, possibly realized with SiGe, are of major interest. As SiGe MMICs in general are fabricated on low-resistivity silicon substrate, differential interconnects allow both reduced line losses as well as better handling of thick substrates. A typical example is a four-channel radar chip at 79 GHz [1].

Even on standard dielectric substrates, microstrip or coplanar lines exhibit non-negligible losses at such high frequencies. One way out of this problem is the use of substrate integrated waveguides (SIW) where a dielectrically filled waveguide is formed in the substrate by rows of vias [2, 3].

This paper investigates a transition between differential microstrip lines and a SIW, integrated on a planar structure. Up to now, some work has been presented concerning planar transitions from microstrip to SIW [3, 4]; recently, a transition from differential microstrip lines to metal waveguide has been proposed [5]; this transition provides excellent results, but is not integrated in a planar form.
To enable a fabrication with the author's own means, a first model transition was designed and tested in the Ka-band.

II. Transition Design

A. SIW-to-Differential Microstrip Transition

The basic idea of the transition is a predominantly electric coupling of the differential signal into a substrate integrated waveguide using two coupling vias (Fig. 1). The transition is composed of at least three substrate layers, the top one is used for the differential microstrip lines, the center and bottom layers form the SIW. The metal layer between top and center substrate provides the ground plane for the differential microstrip lines. The distance between the differential microstrip lines (selected to 100 Ω here) is linearly increased, and both lines are guided into the SIW by vias through two circular apertures within the ground plane and the upper boundary of the SIW, respectively. The penetrating vias have a distance l_1 which is approximately $\lambda_g/2$ and end at the bottom side of the inner substrate layer as illustrated in Fig. 1 (λ_g is the guided TE_{10} wavelength within the SIW at the center frequency). The substrate integrated waveguide is terminated with a backshort formed by a via-wall placed $l_{bs} \approx \lambda_g/4$ away from the adjacent coupling via.

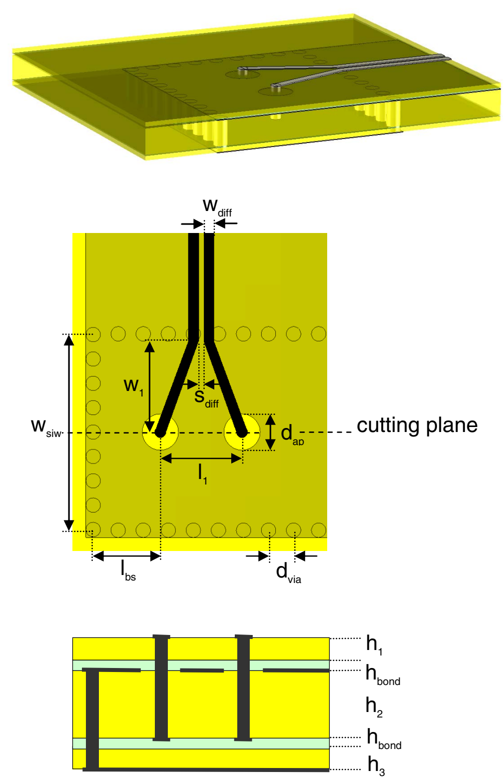

Fig. 1 Configuration of the transition. Design parameters are: w_{diff} = 0.27 mm, s_{diff} = 0.15 mm, l_1 = 2.25 mm, w_1 = 2.5 mm, d_{ap} = 1 mm, d_{via} = 0.69 mm, l_{bs} = 1.85 mm, w_{siw} = 5.4 mm, h_1 = h_3 = 0.13 mm, h_2 = 0.76 mm, h_{bond} = 0.038 mm.

B. Balun

While the transition is intended for use in differential circuits, a balun is necessary in order to characterize the transition with standard single-ended measurement equipment. A passive balun is designed based on the principle published in [6] and optimized for the applied substrate and for an operation in the Ka-band frequency range. The balun structure displayed in Fig. 2 consists of two parts. First, the 50 microstrip line (MSL) is transformed into a 100 coplanar stripline (CPS) using a tapered ground plane. Whilst the MSL forms one conductor of the CPS, a radial stub provides a virtual ground to the second conductor of the CPS at the joint. In a second step the ground plane is reintroduced at a reasonable distance from the MSL ground plane in order to obtain the desired grounded differential mode. The whole structure was simulated and optimized using *CST Microwave Studio*.

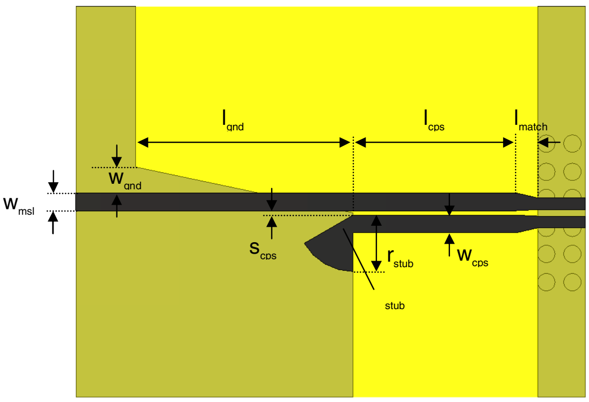

Fig. 2 Configuration of the balun. Parameters: w_{msl} = 0.41 mm, l_{gnd} = 5 mm, w_{gnd} = 0.6 mm, l_{cps} = 3.75 mm, l_{match} = 0.5 mm, s_{cps} = 0.1 mm, w_{cps} = 0.41 mm, r_{stub} = 1.3 mm, θ_{stub} = 60°.

To verify its performance, the balun was fabricated and measured in a back-to-back configuration with two different connecting line lengths. Based on the measured results, the single transition was de-embedded; the results are plotted in Fig. 4. Insertion loss is around 1 dB over the frequency range 25 GHz – 40 GHz including 3 mm of microstrip transmission line.

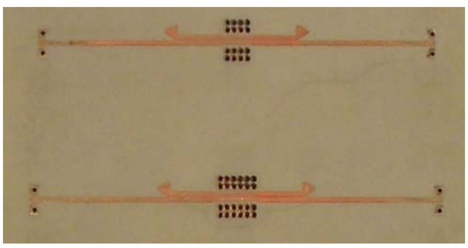

Fig. 3 Photograph of the top layer of the manufactured back-to-back balun transitions.

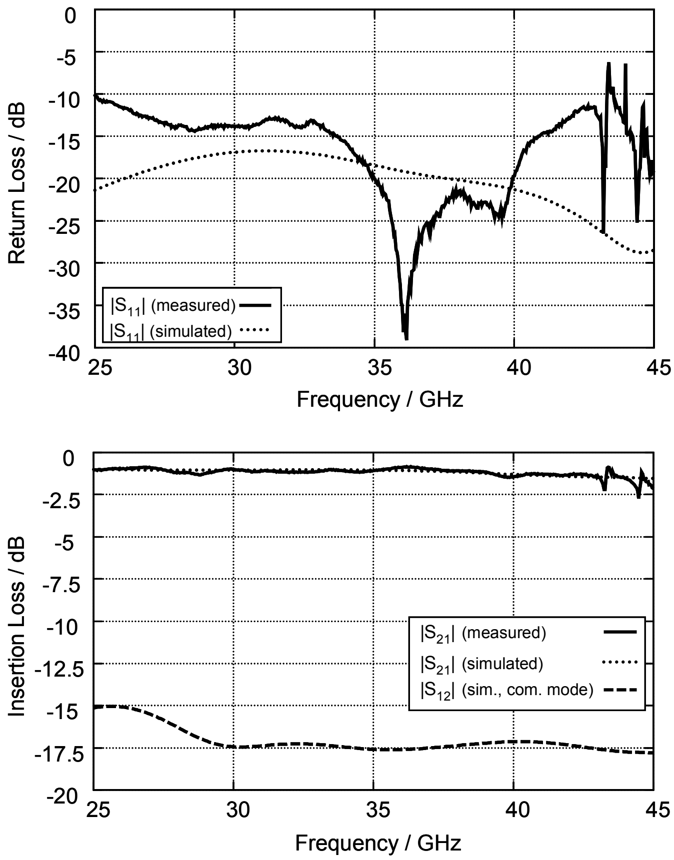

Fig. 4 Simulated and measured (de-embedded) S-parameters of the balun.

III. Manufactured Transition and Characterization

In Fig. 5 the manufactured transitions based on Rogers 3003 substrate material with Rogers 3001 bonding film is shown. Since the manufacturing process did not allow via connections from the bottom substrate to the center substrate, the vias forming the SIW had to be connected through all three substrate layers. Hence, a gap in the SIW had to be left for the differential microstrip lines. This gap is too small to disturb the propagation of the waveguide mode. To avoid a coupling of the CPS lines (without ground plane) to the chuck of the prober station, the whole multilayer was mounted on Rohacell® 51 HF foam with a permittivity of 1.048 and a thickness of 6 mm. Two transitions in back-to-back configuration with slightly different SIW-lengths were manufactured, and the results of a single transition were de-embedded (Fig. 6).

A good agreement can be found for the return loss; 10 dB bandwidth is more than 10 GHz. The measurement still includes the balun. Hence, the insertion loss of the actual transition is approximately 1 dB better than the result shown in Fig. 6. Some problems still occur at higher frequencies, possibly, there may be some radiation, but also some higher-order mode coupling in the back-to-back configuration may have occurred; this still is to be investigated.

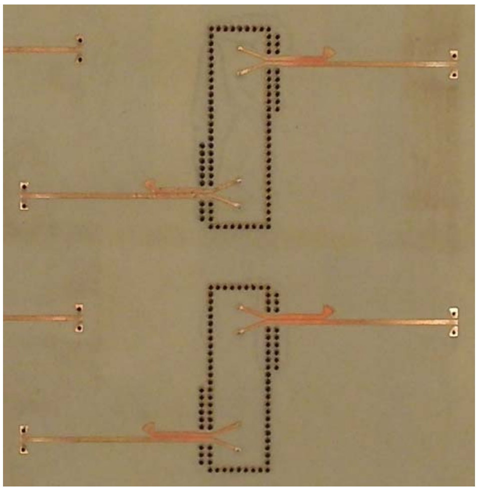

Fig. 5 Photograph of the top layer of the manufactured back-to-back transitions.

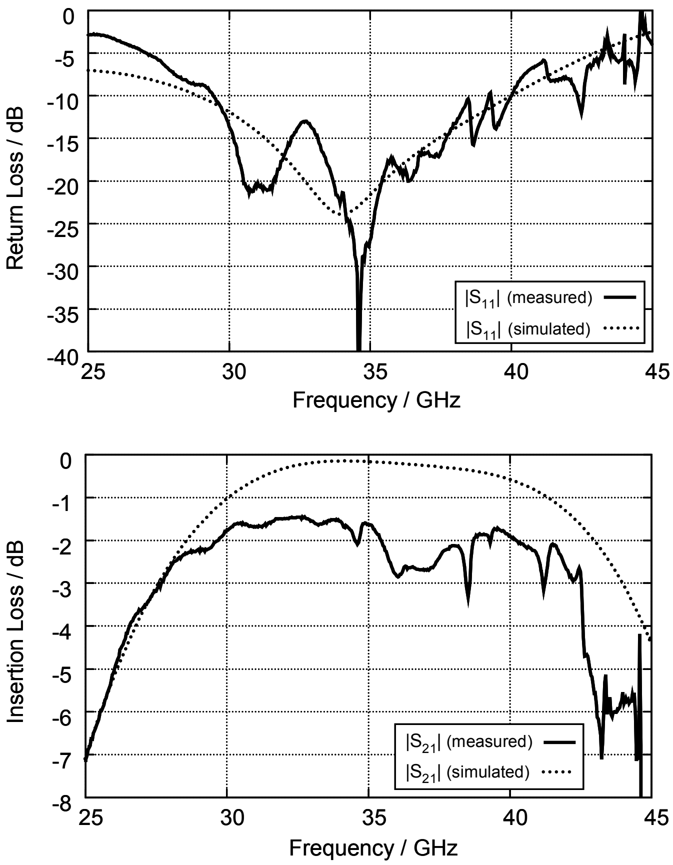

Fig. 6 Simulated and measured (de-embedded) S-parameters of the differential microstrip line-to-SIW transition.

IV. CONCLUSIONS

A first transition from differential microstrip to substrate integrated waveguide has been designed, fabricated, and tested successfully in Ka-band based on standard soft substrates. A 10 GHz bandwidth could be achieved, some investigations are still necessary to reduce radiation of the structure. In future, this design shall be adapted to LTCC and higher frequencies.

ACKNOWLEDGMENT

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