Near Millimeter-Wave Building Blocks Based on Novel Coaxial to SIW Transition

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Abstract. The paper presents a new connection topology intended for flexible integration of substrate-integrated waveguide (SIW) components, based on a building blocks concept, due to configuration circular symmetry and possible location on both SIW wide walls. This type of connection was experimentally validated on a scaled down model made of FR-4 substrate, by using printed circuit board (PCB) technology, with a bandwidth exceeding the regular 5 GHz unlicensed telecommunications frequency range. The measured results are in excellent agreement with simulated two-port parameters. The transition can be made compatible with either surface mounted assembly or miniature coaxial connectors (SMA, K or Q-type) depending on dimension limits vs. frequency range.

1. Introduction

Many passive components have been implemented in substrate-integrated waveguide (SIW) technology, due to reduced insertion loss and radiation compared with their microstrip and coplanar transmission line counterparts, mainly in the mm-wave frequency range. Antennas, directional couplers and especially the filters and frequency diplexers can be mentioned among relevant SIW applications [1]-[5]. The specific structure of these components is based on low loss dielectric substrates, having the wide top and bottom planes covered with thin metal layers which are connected by two periodic arrays of metal plated via holes or metal posts. Due to their dielectric filling, SIW structures can be seamlessly integrated with microstrip or coplanar transmission lines (TL). However, the connection of a narrow TL to the wider SIW component has to be performed with specially designed transition geometries, in order to achieve a broadband response [5]-[8].

The coplanarity condition between input/output coupling lines and the wide upper SIW plane somehow limits the chained components relative placement inside their integration area. Moreover, all system integrated components - including the SIW structures - can not be physically separated for electrical characterization, hence their individual measurement requires either to produce and test them as independent components or to insert line gaps between any two adjacent components, and corresponding ground contacting pads too, all for vector network analyzer (VNA) coupling by using on-wafer test probes. These probes have a fixed range of discrete distance values between contacting fingers, therefore any design should be restricted to it. The gaps can be closed in a subsequent technological process, possibly expensive and hazardous.

A typical example of RF and microwave on-wafer probe family is ACP (Air Coplanar Probe) series [9], with a characteristic ground-signal-ground coplanar waveguide (CPW) configuration.

The paper presents a new approach for microwave and near-millimeter wave systems integration by utilizing a recently developed transition from miniature coaxial connectors to SIW structures [10], which can be adapted as a component connection mean, more flexible regarding the transmission line interfaces intended to form a junction, compared with presently used connection types. The proposed transition can be also tested from reliability point of view, mainly for stand-alone SIW components used in lower frequency applications.

2. The Novel Coaxial to Siw Transition

The usual coupling structures to a SIW component (Fig. 1) consist of folded extension slots for coplanar lines [5]-[6] and tapered (linear or stepped) transitions in case of microstrip lines [6]-[8].

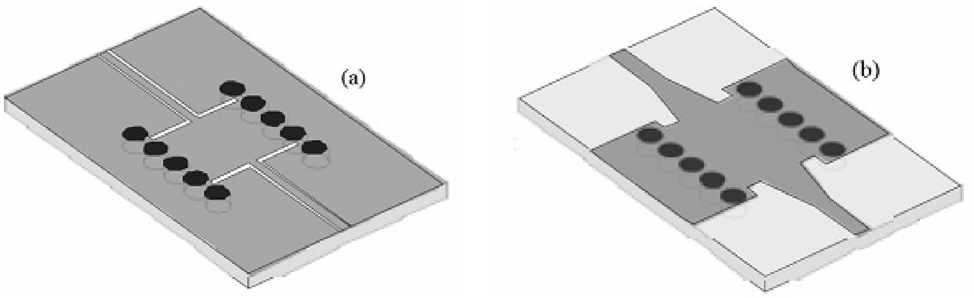

Fig. 1. Example of SIW transitions to coplanar line (a) and to microstrip line (b)

The distinctive element defining the novelty of coaxial to SIW transition is the probe coupling structure placed inside the SIW area, at certain offset from the longitudinal guide axis (PBO) and distance (PBD) from the end-of-guide shorting wall (Fig. 2).

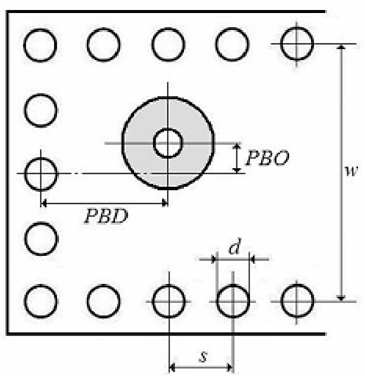

Fig. 2. The offset probe used for coaxial-to-SIW transition (bottom view).

The probe configuration, with minimum two metal plated cylindrical coaxial sections, usually having different diameters, is presented in Fig. 3. One probe end - detail (1) in Fig. 3, surrounded by an annular copperless area - detail (2) in Fig. 3, identifies the signal transfer „top" plane port. A small circular pad, electrically connected to each „top" probe end, has to be provided for reliable assembly. The other probe end is connected to the ground „bottom" plane, so that the microwave signal does not pass through it.

Both „top" and „bottom" definitions here are circumstantial ones, but they help us to have a reference plane for the only possible signal transfer place within a given transition. This probe design does not incorporate any other hidden or exposed element (either metal or dielectric), therefore the processing technology is maintained simple and fully compatible with all SIW components containing only metalized via holes, mainly filters and diplexers.

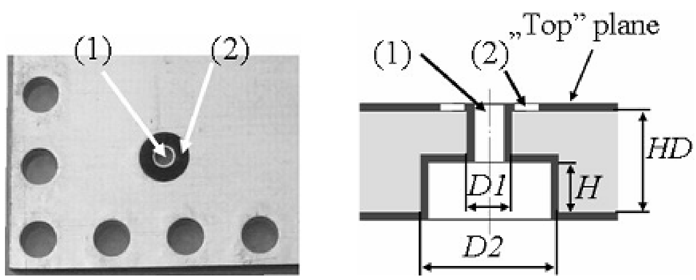

Fig. 3. Coupling probe details: "top" probe end, also connector's center insertion point (1); annular copperless area (2).

In case of an n-port SIW circuit ($n \geq 2$), the „top" plane of a coupling structure can become the „bottom" plane of any other coupling structure, if the system design requires it, thus contributing to the overall assembly flexibility.

In other words, any transition may be placed upon any of two available SIW's wide walls. Additionally, due to its circular symmetry, the transition allows free angular relative positioning of two coupled circuits.

3. Building Block Concept

The coaxial-to-SIW coupling structure described above is not polarized, *i.e*. two similar transitions can be paired if their top probe ends are collinear and corresponding ground pads or areas are available, without any restriction related to the transmission line type at the other transition end.

This property permits us to imagine a spatially assembled structure (Fig. 4) composed not only by SIW „bricks" but also of other components using traditional planar transmission lines. The following conditions apply: (i) all circuits are provided with compatible transitions or probes, (ii) the connecting probes are coaxial and (iii) unobstructed mechanical contacts are required for soldering purpose.

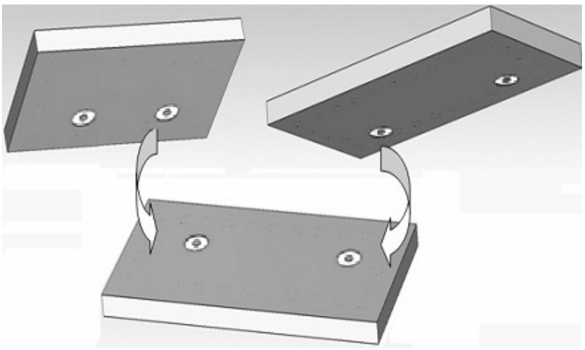

Fig. 4. Illustration of building blocks concept.

Some microwave components assembled on circuit boards having microstrip or grounded CPW signal transmission lines can be also made compatible with the new coaxial-to-SIW transition, as surface mounted devices. In this case, all microwave signal connection pads should be embedded in the bottom ground plane, similar to the coupling probe details presented in Fig. 3 for a miniature coaxial connector. The new top-to-bottom via hole has an inductive behaviour, requiring a carefully designed reactance compensation.

4. Simulation Results

Certain limits are expected regarding available working frequency bands due to dimension constraints introduced by finite diameter measure of the coaxial connectors' center conductors: 0.305 mm for K-type and 0.24 mm for V-type models. Also, some technological restrictions may occur in case of building block assembly of surface mounted components. Consequently, starting with general design rules [8], a test circuit containing a short SIW segment inserted between two coaxial to SIW transitions was proposed for analysis and optimization.

The simulation process was based on the characteristic SIW dimensions presented in Fig. 2, the target bandwidth covering full 23.5-30 GHz frequency range, so that both 24.0 to 24.25 GHz (ISM band) and approx. 26 to 30 GHz (MMDS band - USA) possible applications could benefit from the optimization results. CST Studio Suite™ [11] simulation and optimization software was used for the entire project development.

The following constant parameters were chosen for this design:

d (via diameter) = 400 μm

s (via pitch) = 1000 μm

w (distance between via rows) = 4000 μm

HD (dielectric height) = 900 μm

ε_r (relative permittivity) = 5.9 (lossy A6M Ferro dielectric material) The simulated circuit response, after optimization of PBO, PBD, D1 and D2 variables as listed below, is presented in Fig. 5.

PBO = 820 μm

PBD = 1650 μm

D1 = 300 μm

D2 = 1045 μm

H = 450 μm

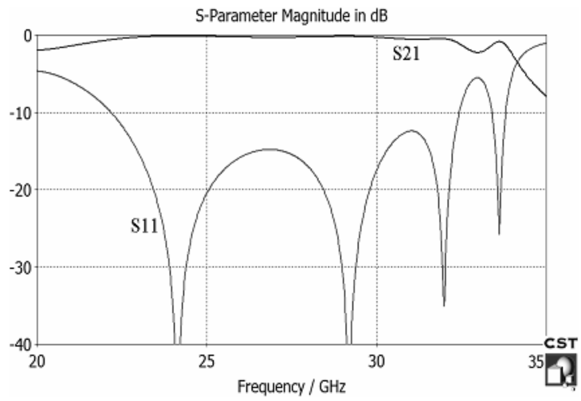

Fig. 5. Simulation results for the 26-30 GHz transition model.

The height H was considered to be half of the dielectric substrate height, although it may be changed by other optimization runs if the technological processes, like multi-layer low temperature co-fired ceramic (LTCC), tolerate to define a certain value range, usually with discrete values.

5. Experimental Results and Model Validation

The structure presented in previous section was scaled down to 5 GHz frequency band and produced of regular FR-4 material, in order to validate the proposed concept. The circuit is presented in Fig. 6, after SMA connectors assembly.

The scaled SIW dimensions are: d = 3 mm; s = 6 mm; w = 24 mm; HD = 5 mm. The corresponding results after structure optimization are PBO = 5.5 mm, PBD = 10 mm, $D2$ = 8 mm, while the probe dimension H is half of dielectric height. The external diameter of annular copperless area was decided according to 50 Ω SMA connector dielectric outer nominal diameter (about 4 mm) and D1 = 1.5 mm (it allows insertion of 1.27 mm SMA center conductor).

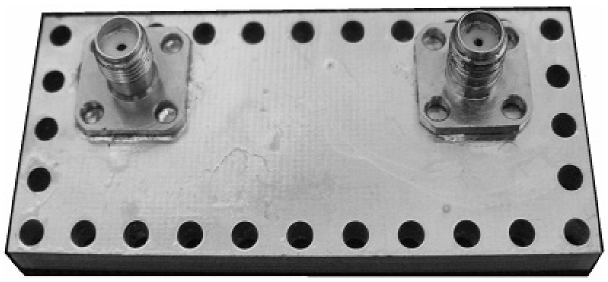

Fig. 6. The scaled test structure (5GHz band).

The measured circuit response shows an excellent agreement with simulated behavior (Fig. 7), consequently confirming the possibility to extend the use of the new transition type for flexibly structured mm-wave circuits based on SIW components.

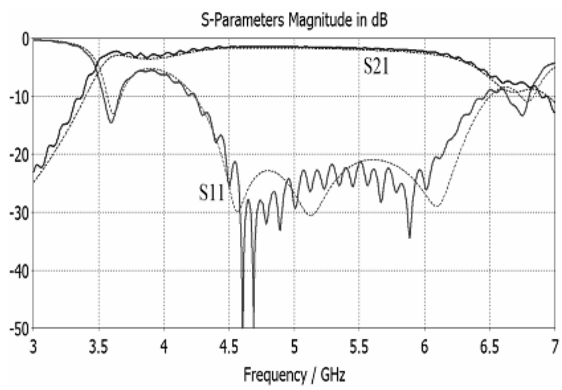

Fig. 7. S parameters of the scaled model: measured (continuous lines) and simulated values (dotted lines).

6. Conclusions

A new and flexible solution for SIW structures connection to other components, having either similar or different transmission line interfaces (coaxial line, microstrip, CPW), has been presented. The placement of these transitions is not more restricted to the top of SIW components, as it happens with present coupling sections to planar transmission lines, so that it can be located on each of wide SIW walls, depending on particular requirements. A scaled down model was produced by using PCB technology on FR-4 substrate; the measured results are in excellent agreement with circuit simulations. It is expected that the proposed solution could be also extended to surface-mounted components.

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[11] *** CST Studio Suite TM software modules