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Wideband Transitions from Substrate-Integrated Waveguide to Coupled Microstrip Lines and Their Applications to Power Dividers

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Abstract — **Three wideband transitions from Substrate-Integrated Waveguide (SIW) to Coupled Microstrip (CMS) lines are presented. It is demonstrated that a transition from the fundamental SIW mode to the even quasi-TEM mode of the CMS is straightforward, whereas dominant coupling to the odd mode is only realizable by removing parts of the ground plane. Asymmetric transitions maintaining the ground plane excite a hybrid mode which includes both quasi-TEM modes of the CMS. For this hybrid mode, the excitation ratios between the even- and odd-mode components can be varied, and an unequal power divider is obtained. Performances of the individual transitions and power divider are verified by commercially available field solvers. Dimensional parameters are provided.**

Index Terms — **Substrate-integrated waveguide, coupled microstrip line, transitions, interconnects, power dividers.**

I. Introduction

Following the introduction of the Substrate-Integrated Waveguide (SIW) concept in 2001 [1], substrate-integrated circuits have emerged as a mature technology [2] that continues to replace all-metal waveguide components whenever a slight increase of overall loss is acceptable. For integration of SIW with active and/or surface-mounted devices, interconnects to other, preferably planar transmission-line media, are required. Therefore, a number of such transitions have been investigated and proposed.

The most commonly used interconnect is the SIW-to-microstrip transition [3] whose design guidelines are readily available [4]. Other interconnects include transitions to grounded coplanar waveguide (GCPW) [5], regular coplanar waveguide (CPW) [6], coplanar strip (CPS) line [7] and slotline [8]. To the best of the authers' knowledge, a direct transition from SIW to coupled microstrip (CMS) lines has not been attempted.

Therefore, this paper focuses on the design of three wideband interconnects from SIW to CMS and their applications to power dividers. A symmetric transition, which excites the even mode of the CMS, is straightforwardly designed. In order to excite the odd mode, parts of the ground plane are removed. The interface of the fundamental SIW mode with a combination of even and odd modes in the CMS (a so-called hybrid mode) is used as a power divider example.

II. Transitions Design

The interconnects in this paper are designed on Rogers RT/Duroid 6002 substrate with ε_r=2.94, tanδ=0.0012, substrate height h=0.508mm, metallization thickness t=17.5μm, and conductivity σ=5.8x10^{7}S/m. The bandwidth of operation is 18 GHz to 28 GHz. The width of the SIW in Fig. 1 is W_{SIW}=6.7mm, and the via hole diameter and center-to-center spacing are 0.62mm and 0.86mm, respectively. The CMS lines have strip widths of W_{CMS}=0.84mm and strip separation (slot width) of W_S=0.15mm as dictated by typical fabrication restrictions.

The design proceeds as follows. For an effective microstrip line width that combines the two strips and the slot ($W_{EFF}=2W_{CMS}+W_S$), an SIW-to-microstrip transition is designed according to [4]. For the symmetric transition to the CMS's even mode (Fig. 1a), the transition parameters W_{T1}, W_{T2}, L_{T1}, L_{T2} are optimized for a return loss of better than 20dB over the entire band of operation. For the asymmetric transitions in Fig. 1b, the optimization goals for the transition are set to excite the even component in the CMS at a higher level than the odd one and, at the same time, to maintain the

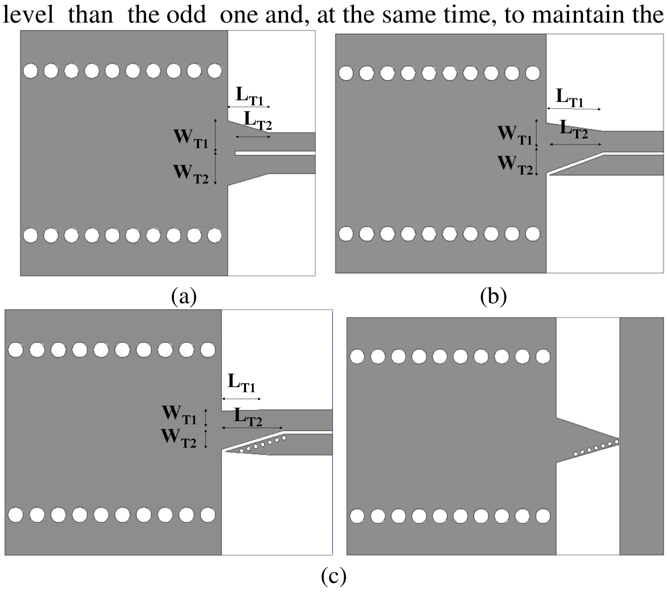

Fig. 1. Wideband transitions from SIW to CMS to excite the (a) even mode, (b) a hybrid mode, and (c) the odd mode with top (left) and bottom (right) metallization viewed from the top.

return loss specifications.

In order to accomplish a dominant odd mode excitation, two additional features are required (Fig. 1c): First, one of the coupled microstrip lines is separated from the top metallization and connected to the ground plane by a row of five small via holes. Secondly, the ground plane has to be removed and reintroduced later in the transition in order to aid a rotation of the electric field which is perpendicular to the substrate in the SIW and parallel to the substrate in the odd mode of the CMS.

The transition performance is verified by the time-domain hexahedral-mesh solver of CST and by HFSS. The dimensions of the three interconnects displayed in Fig. 1 are tabulated in Table I.

TABLE 1
DIMENSIONS OF TRANSITIONS IN MM

	W_{SIW}	W_{CMS}	W_S	L_{T1}	L_{T2}	W_{T1}	W_{T2}
Fig. 1a	6.7	0.84	0.15	1.71	1.4	1.32	1.32
Fig. 1b	6.7	0.84	0.15	2.4	2.4	1.27	0.80
Fig. 1c	6.7	0.84	0.15	2.0	2.5	0.8	0.68

III. RESULTS

Fig. 2 displays the performance of the SIW-to-CMS transition according to Fig. 1a. Due to its symmetric character, only the even mode in the CMS is excited. The maximum insertion loss to convert the fundamental TE_{10} mode of the SIW to the even mode of the CMS occurs at the lowest frequency and is 0.185dB as computed with both CST and HFSS. The return loss is better than 24dB, and a very good agreement between CST and HFSS is observed. It is obvious that a separation of the two microstrip lines at the end of the transition will result in a symmetric 3dB power divider with microstrip output ports (not shown here for lack of space).

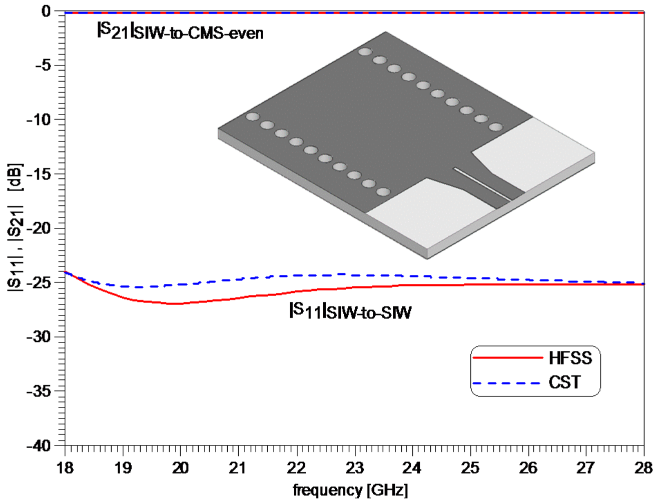

Fig. 2. Performance of the symmetric transition from SIW to CMS (Fig. 1a) to excite the even mode.

The performance of the transition from the SIW to the hybrid mode of the CMS (containing both even- and odd-mode components) is shown in Fig. 3. Due to the separation of one of the microstrip lines from the top metallization of the SIW, the field in the CMS will contain a dominant even part but also an odd part which results from the asymmetry of the transition. Fig. 3 depicts the level of the even-mode excitation as between -1.5dB to -1.8dB while that of the odd mode is -5.4dB to -5.9dB. At the lower frequencies of the band, the return loss values are slightly below 20dB, namely 19.2dB as simulated with CST. However, from 18.9 GHz onward, the return loss remains below 20dB. HFSS predicts the return loss to be better than 20dB over the entire band.

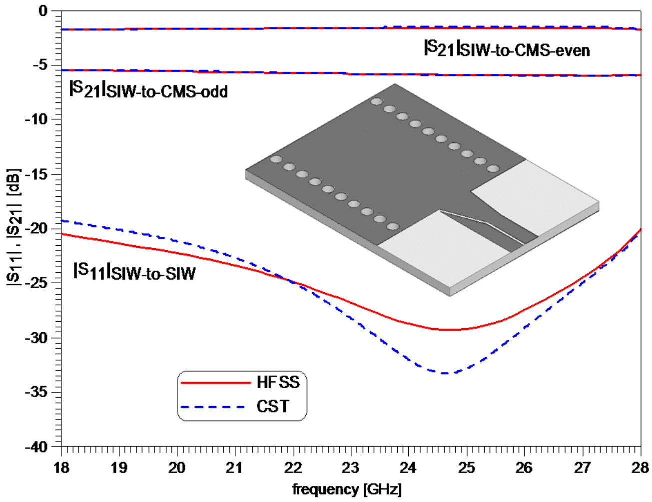

Fig. 3. Performance of the asymmetric transition from SIW to CMS (Fig. 1b) to excite the hybrid mode with dominant even-mode component.

The performance of the transition depicted in Fig. 1c to excite the odd mode of the CMS is shown in Fig. 4. The ground metallization is partly removed and via holes are used, whereby the even mode is significantly suppressed. Its transmission coefficient increases between 18 GHz and 28

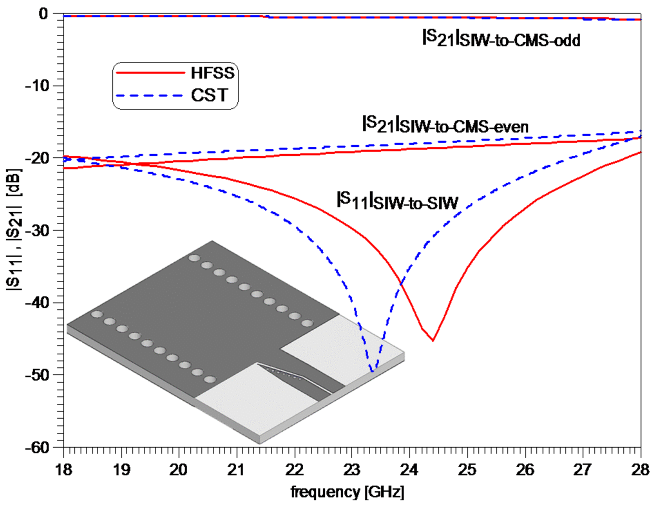

Fig. 4. Performance of the asymmetric transition from SIW to CMS (Fig. 1c) to excite the odd mode of the CMS.

GHz from -20.5 to -16.3 dB in CST and from -21.5 to -17.3 dB in HFSS simulations. The maximum insertion loss of the odd mode occurs at the highest frequency and is calculated as 0.87 dB in CST and 0.83 dB in HFSS. The minimum of the reflection coefficient differs by about 1 GHz between CST and HFSS at a level below 40 dB, but both software packages simulate the return loss to be better than 17 dB over the entire band and better than 20 dB over most of the band.

The structure of Fig. 1b is used to implement an uneven 10 dB power divider with 50 Ω microstrip ports. The dimensions are shown at the top of Fig. 5. The performance comparison between CST and HFSS simulations is very good. Over the 10 dB coupling range between 22 GHz to 26 GHz, the return loss is better than 19 dB, and the insertion loss is 1.3 dB. The power division ratio can be controlled by the transition to a certain degree. However, ratios requiring a higher odd-mode component will have to incorporate via holes such as shown in Fig. 1c (left).

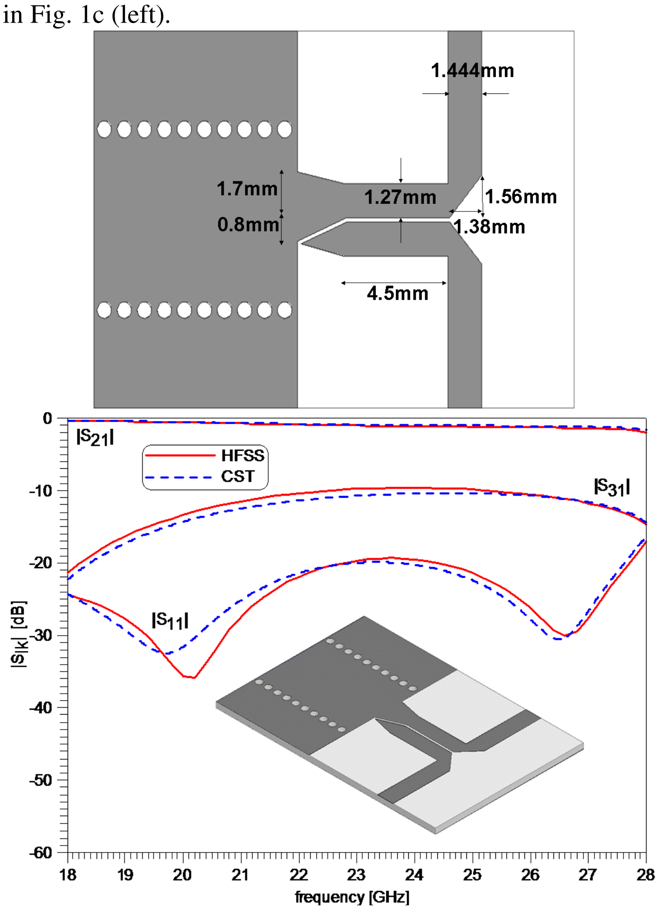

Fig. 5. Dimensions and performance of an asymmetric transition from SIW to CMS (Fig. 1b) operating as a 10 dB power divider.

IV. Conclusions

The designs of three interconnects from SIW to the coupled microstrip (CMS) line are presented, and their performances are verified over a 10 GHz bandwidth centered at 23 GHz (43 percent). It is demonstrated that a symmetric transition excites the even mode in the CMS. It is found that a dominant odd-mode excitation requires via holes and a partly removed ground plane. An asymmetric transition without via holes excites a hybrid mode consisting of an even-odd-mode ratio of about 4 dB. All three transitions feature return-loss values in the order of 20 dB or better as validated by two commercially available field solver packages. Design and implementation as an uneven power divider points to a direct application of the transitions between substrate-integrated waveguide and microstrip technologies. An example circuit operating from 22 GHz to 26 GHz shows 10 dB power division, 19 dB return loss, and 1.3 dB insertion loss.

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