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Planar Transitions from Substrate Integrated Coaxial Line to Single-Layer Transmission Lines and Waveguides

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***Abstract* — This paper presents inline transitions from substrate integrated coaxial line (SICL) to microstrip line, coplanar waveguide (CPW), as well as substrate integrated waveguide (SIW). A common property is conversion of the structure from double substrate layer to single substrate layer of PCB. The first two transitions can be used from DC up to the presence of higher order modes if the characteristic impedances of two meeting transmission lines are matched. The transition to substrate integrated waveguide is of higher complexity, yet compact. Both sides of the SICL-SIW transition are strongly coupled to resonant cavity, and return loss greater than 20 dB is achieved in fractional bandwidth of 10.91 %.**

Index Terms — adapter, substrate integrated coaxial line (SICL), substrate integrated waveguide (SIW), transition, waveguide

I. Introduction

While many transmission lines such as microstrip or coplanar waveguide (CPW) had originally been introduced as planar, some of the oldest known wave-guiding structures have more recently been utilized in their flat forms, which are easier for fabrication and integration. The best-known is the substrate integrated waveguide (SIW) [1]. Nevertheless, SIW possesses some properties that are not desirable in all applications, like high-pass frequency characteristic and dispersiveness. Substrate integrated coaxial line (SICL) [2] is likewise a shielded structure, nevertheless, TEM mode can propagate inside it from zero frequency in wide frequency band of single-mode operation, and is nondispersive. These properties provide potential for multichannel SICL arrays to be used for densely integrated high-speed parallel data transmission with low crosstalk and low phase distortion [3].

Although significantly smaller in number than in the case of SIW, different microwave components such as couplers [4]-[5],[2], filters [6]-[8], and baluns [9] have been implemented in SICL technology. SICL is also often applied in feeds of versatile planar antennas [10]-[13]. They involve diverse and complex functionalities and topics like balun elimination, antenna arrays, specific linear and circular polarizations, multiband and wideband operation, as well as frequencies above 70 GHz.

For its practical application, there is particular importance in integration of SICL with other transmission lines and waveguides. So far, transition to 2-layered grounded coplanar waveguide (GCWG) has been analyzed [14] and commonly used for mounting coaxial connectors [5],[7],[9],[14]. Transitions to metal waveguide [15],[13] and SIW [16] can be found introduced in literature as well. Here, some further essential transitions to single layered transmission lines will be tested and a new transition to single layered SIW is proposed. All the designs have been full-wave simulated in CST Studio Suite [17].

II. Planar Transmission Line Adapters

With microstrip being the most widely used planar transmission line, a transition between it and SICL is crucial for functionality of SICL, and can be used for measuring responses of SICL structures. Even though same characteristic impedance does not guarantee absence of reflection when transmission lines with different cross sections and electromagnetic field distributions are interconnected, there is no noteworthy problem of that kind here. This could have been anticipated knowing that coaxial connectors are regularly directly joined to microstrip lines.

In Fig. 1. is shown SICL to microstrip adapter designed for 0.787 mm thick Rogers RT/duroid® 5880 substrate with 18 μm thick copper cladding. This sample piece of PCB adapter has 20 mm x 20 mm footprint. Both transmission lines have standard 50 Ω characteristic impedances, thus W_{MS} =2.4 mm and W_{SICL} =1.3 mm (designed with 0.1 mm precision).

In addition, the spacing between vias in the opposite sides of the outer conductor of SICL they form is a_{SICL} = 5 mm, so that the cutoff frequency for the here parasitic TE_{10} mode is above 20 GHz. We can draw a parallel between TE_{10} higher mode in SICL as SIW dominant mode and TE_{11} mode in conventional coaxial cable, as the dominant mode in circular waveguide. All vias have the diameter of $D = 0.6$ mm and the pitch is $p = 1$ mm.

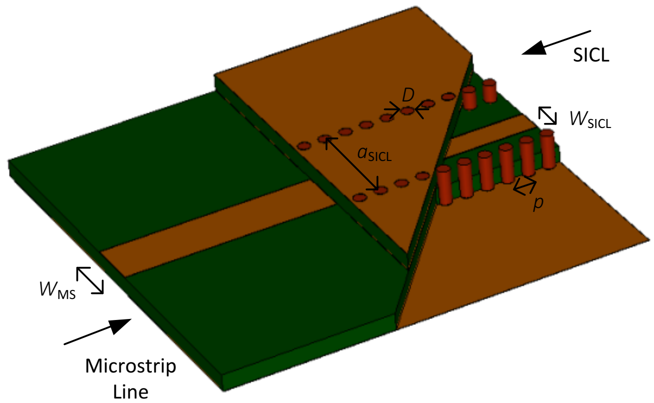

Fig. 1. Layout of transition between microstrip and substrate integrated coaxial line.

In Fig. 2. Are given wideband frequency responses of the adapter, between 0 and 20 GHz. The skin effect and effect of surface roughness in copper cladding are modeled to be accurate in the entire frequency span. As expected, with the rise in frequency the adapter has dominantly linear trend of increased transmission losses on dB scale, as well as higher input reflections.

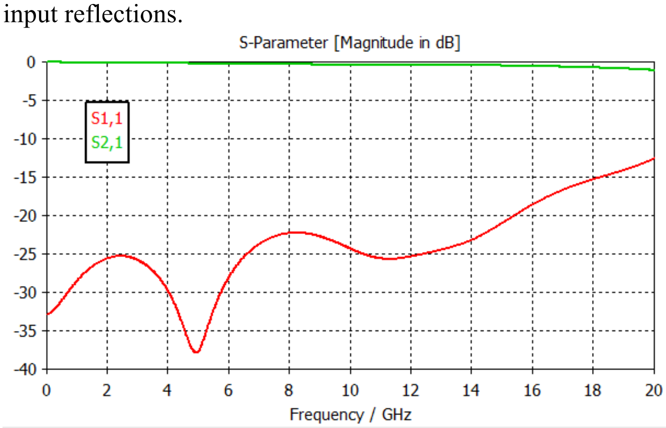

Fig. 2. S-parameters of transition between microstrip and substrate integrated coaxial line.

When microstrip line is replaced with grounded coplanar waveguide (Fig. 3), the only new dimension is the top conductor width of GCPW, W_{CPW} =1.9 mm, when widths of gaps between this conductor and the side groundplanes are set to S =0.3 mm. Simulated S-parameters (Fig. 4) are also visually similar, although performance is slightly worse.

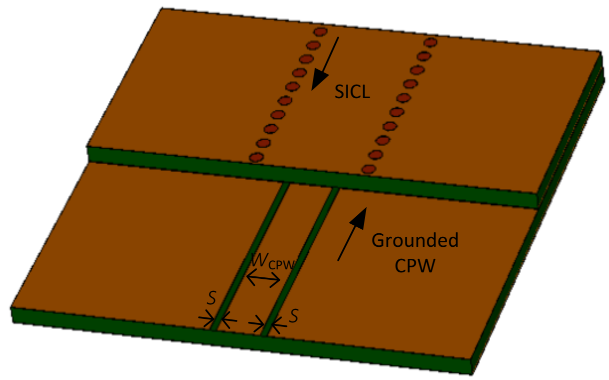

Fig. 3. Layout of transition between coplanar waveguide and substrate integrated coaxial line.

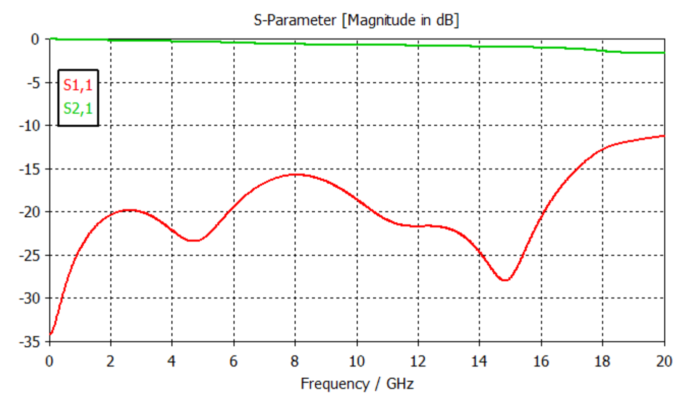

Fig. 4. S-parameters of transition between coplanar waveguide and substrate integrated coaxial line.

III. Planar Waveguide Adapter

The transition between SICL and SIW cannot be simply made by matching characteristic impedances, but uses a substrate integrated cavity as intermediate element, to which both sides are strongly coupled. As it can be seen from Fig. 5. that presents lossless structure with PEC walls instead of vias, the cavity has double substrate thickness. Dielectric loaded waveguide that represents SIW is coupled to it with its full width, but just in single substrate layer, whereas rectax that can be seen as enclosed stripline and represents SICL is coupled through a loop implemented by a via that short-circuits the center SICL conductor to the top broadwall.

It is critical that the inner conductor is connected to only one of opposite side wall (it is a broadwall because of the symmetry with respect to the SIW E-plane), because otherwise magnetic fields from two loops would be cancelling each other. The inner conductor section inside the cavity and the via connected to it are wider in order to enhance coupling. Furthermore, the transmission is improved by using another independent via in singe substrate layer deeper in the cavity, but connected to the opposite broadwall.

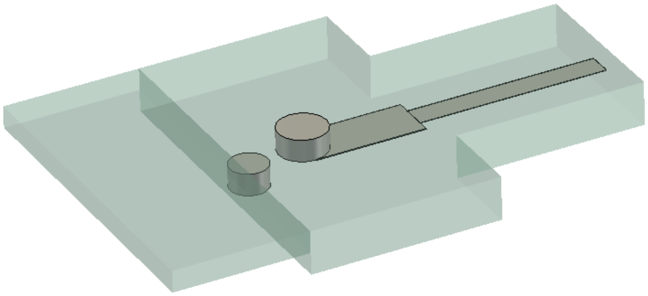

Fig. 5. Ideal model of transition between planar dielectric-filled waveguide and rectangular coaxial line.

In Fig. 6. can be found layout of the adapter implemented with vias. Here, the adapter is designed at X band for 0.813 mm thick Rogers RO4003C substrate, but via diameters are still $D = 0.6$ mm, whereas the distance between adjacent vias in walls is variable, but kept bellow $2D$ limit to prevent signal leakage [1]. It is assumed that the top and bottom side of the dual-layer PCB are entirely metallized.

Simulation results of the SICL-SIW adapter (Fig. 7) show typical resonant shape. S_{11} is bellow -20 dB between 10.07 GHz and 11.23 GHz, which is 10.91 % fractional bandwidth.

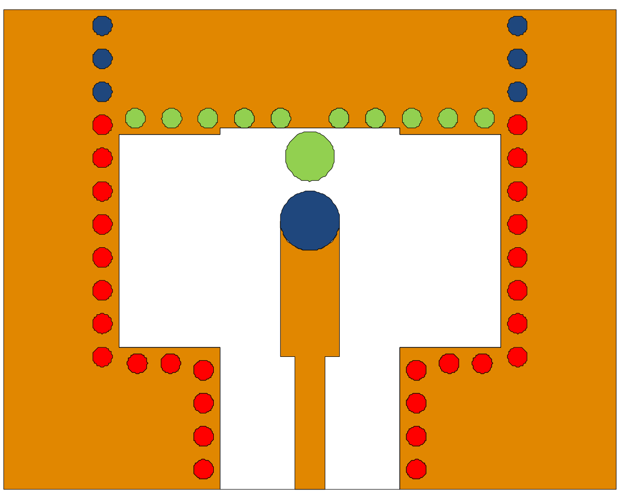

Fig. 6. Layout of the inner conductor (orange) of the transition between substrate integrated coaxial line and substrate integrated waveguide. Through hole vias are in red, vias just in the top layer in blue, and vias only in the bottom substrate layer in green.

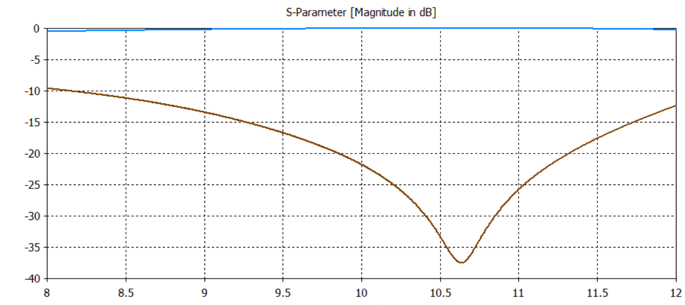

Fig. 7. S-parameters of transition between substrate integrated coaxial line and substrate integrated waveguide.

IV. Conclusion

As transitions between different transmission lines and waveguides are fundamental for usefulness of a wave-guiding structure, the presented adapters between the substrate integrated coaxial line and microstrip line, coplanar waveguide and substrate integrated waveguide demonstrate strong support for use of SICL in microwave circuits. All simulations have shown good convergence with respect to increased mesh refinement and accuracy in increased number of frequency points.

Acknowledgement

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