

E-Plane Directional Couplers in Substrate-Integrated Waveguide Technology

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INTRODUCTION

As a reasonable compromise between microstrip and rectangular waveguide circuitry, substrate-integrated waveguide (SIW) technology has found many applications in the lower millimeter-wave frequency range, e.g. [1], [2]. One of the advantages for the design of SIW components is that after dispersion characteristics and via hole dimensions have been related to all-dielectric-filled rectangular waveguides [3], traditional waveguide design strategies [4], [5] can be employed. Moreover, tapers to microstrip technology [6] provide an interface to measurement equipment. However, the taper itself is often as reflective as the SIW component under test and, therefore, influences significantly the measured results.

Due its planar nature, SIW applications are preferably fabricated in H-plane circuitry. Filters, diplexers, power dividers and H-plane couplers are some of the preferred components, e.g. [1], [2], [7] – [9]. In order to integrate this technology with two dimensional antenna arrays [10], however, coupling between stacked SIW components must be facilitated. So far, only moderate attempts have been made towards multilayered substrates [11] and E-plane couplers [9] for SIW antenna feed networks.

Therefore, in this paper, we present new E-plane coupler designs in SIW technology (e.g. Fig. 1). Moreover, through comparison with SIW-to-microstrip transitions, we demonstrate that an all-dielectric waveguide port is better suited to model the performance of individual SIW components within an entire SIW system. The designs are performed within an HFSS environment which is verified by comparison with measured and computed E-plane slot couplers and microstrip-to-SIW transitions available in the literature.

COUPLER DESIGN AND COMPARISON

The initial design of E-plane waveguide couplers is performed according to [4] and linked to a mode-matching approach [5]. The dimensions are then translated for substrate-integrated waveguide application [3] and fine-optimized using a general field-solver package, e.g. HFSS. A similar procedure has also been used in [9]. In order to compare our results with measurements in [9] for an E-plane 3dB coupler with 14 pairs of circular apertures, microstrip-to SIW transitions (not specified in [9], but designed according to [6]) had to be included at all ports. The results of this comparison are reported in Fig. 2. Reasonable agreement is observed generally. During this process, however, it was found that the coupler performance depends to a large degree on the microstrip-to SIW transitions and their distance to the closest aperture pair of the coupler. It is thus concluded that the microstrip-to SIW transitions mask the actual performance of the coupler.

Therefore, two back-to-back microstrip-to SIW transitions separated by a length of SIW have been recalculated. The comparisons with [6] and [12] are displayed in Fig. 3. Good agreement between our HFSS simulations and the reference data is obtained. However, it is noticed that in both cases, the return loss of the microstrip-to SIW transitions is in the order of 15 – 20 dB. This is certainly not acceptable if SIW components are to be designed for values of 20 dB or better as the transitions considerably degrade the performance of any practical SIW circuit. Also shown in Fig. 3 (as light solid lines) are the return losses of same lengths of SIWs but with the microstrip-to SIW transitions replaced by all-dielectric rectangular

waveguide ports. It is obvious that the return loss is quite significantly improved when using these ports. Therefore, they are better suited to evaluate the performances of SIW components within a SIW environment.

COUPLER RESULTS

Based on the previous investigations, we are confident that the coupler performances presented in this section are valid and minimally influenced by the transitions. The designs use SIW parameters of $a = 5.524$ mm, $b = 0.508$ mm, $p = 2.397$ mm, $d = 1.198$ mm, $t = 35$ μm , $\epsilon_r = 2.2$, where a is the equivalent waveguide width, b is the substrate height, p the center-to-center via-hole distance, d the via-hole diameter, t the metallization thickness and ϵ_r the relative permittivity of the substrate.

In comparison with Fig. 2, we present in Fig. 4 a 10-dB and a 3-dB dual-circular-aperture E-plane coupler as used in [9]. The configuration of the 10-dB coupler with six aperture pairs is depicted in Fig. 1(b). Its performance in Fig. 4(a) shows that the return loss and isolation are better than 22dB and that the coupling is fairly constant over the entire Ka-band.

Fig. 4(b) shows the performance of the 3dB coupler that uses 23 coupling sections to cover the entire Ka-band. It is obvious that the new all-dielectric waveguide ports interface ports allow the component to be designed with better than 24 dB return loss and isolation. This is a value one would expect from a coupler embedded in an all-SIW system.

Fig. 5 shows the performance of a six- and an eight-section Riblet-Saad coupler according to Fig. 1(a). The eight-section design covers the entire Ka-band frequency range with return loss and isolation better than 20 dB. The coupling cannot, of course, remain constant over the entire band, but its performance is fairly flat in the center range of the band and similar to that of typical rectangular waveguide designs towards the band edges.

CONCLUSIONS

In order to analyze and design components in substrate-integrated waveguide technology, it is important that the transitions to interface ports do not significantly influence the component's performance. In this paper, it is demonstrated that the commonly used microstrip-to-SIW transitions are not sufficient to evaluate a SIW structure within a SIW environment. Therefore, we present all-dielectric rectangular waveguide interface ports that considerably reduce the reflections at the transition to the SIW component.

These new ports are then applied to the design of SIW E-plane couplers, both with standard dual-circular apertures and as Riblet-Saad couplers. It is demonstrated that SIW couplers with return loss and isolation of much better than 20dB can be designed. Several 10db and 3dB couplers covering the entire Ka-band frequency range are presented. The basic design procedure is validated by comparison with measurements and computations available in the common literature.

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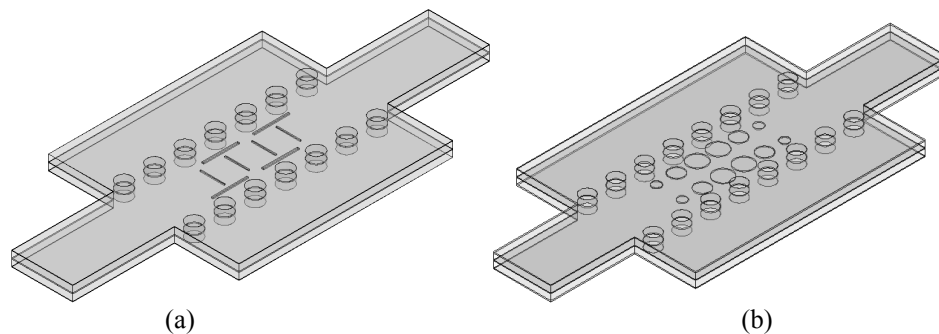
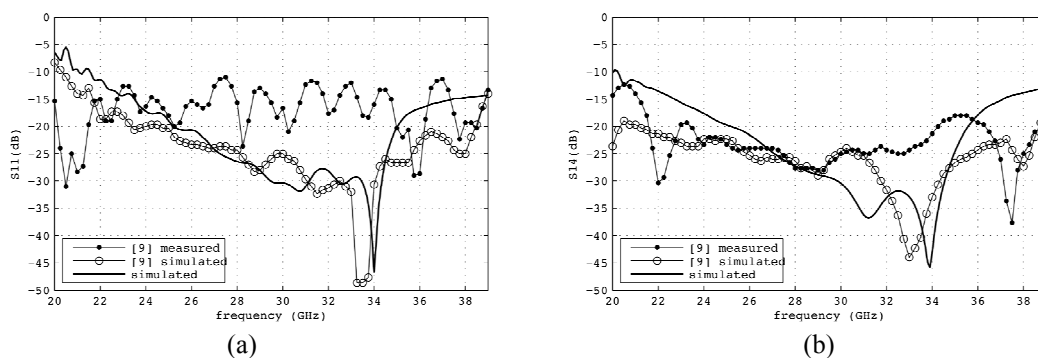


Figure 1. Configuration of a four-section E-plane Riblet-Saad coupler (a) and a six-section circular aperture E-plane coupler (b) in SIW technology using all-dielectric waveguide interface ports.



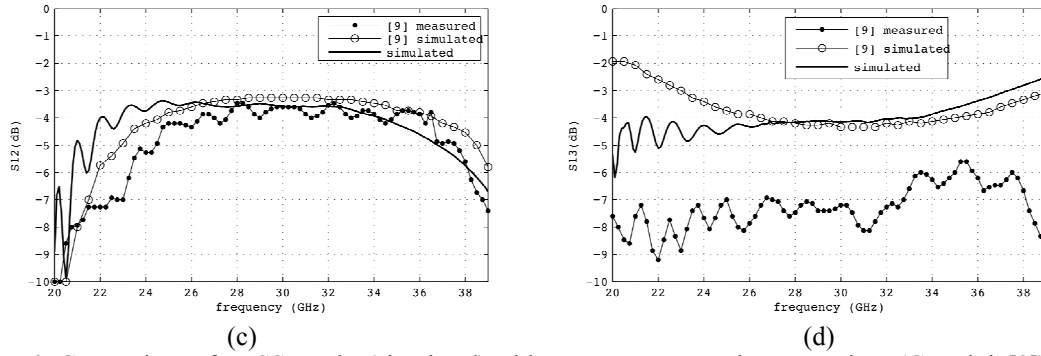


Figure 2. Comparison of HFSS results (simulated) with measurements and computations (Cassivi, [9]) of SIW E-plane 3dB coupler with 14 pairs of circular apertures; microstrip-to SIW transitions included at all ports; reflection at input (a), isolation (b), through port (c), coupling (d).

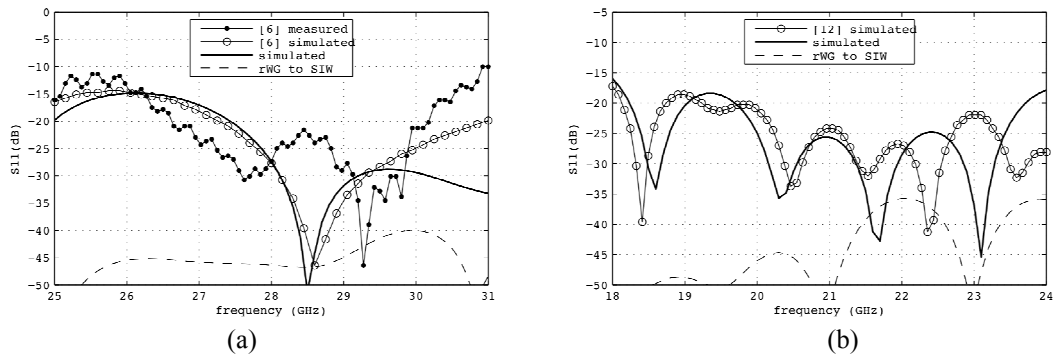


Figure 3. Comparisons of HFSS results (simulated) with measurements and computations (Deslandes [6], (a) and simulations (Wood [12], (b)) of back-to-back microstrip-to SIW transitions separated by a SIW section, and when microstrip-to SIW transitions are replaced by all-dielectric rectangular waveguide ports (rWG to SIW) as shown in Fig. 1.

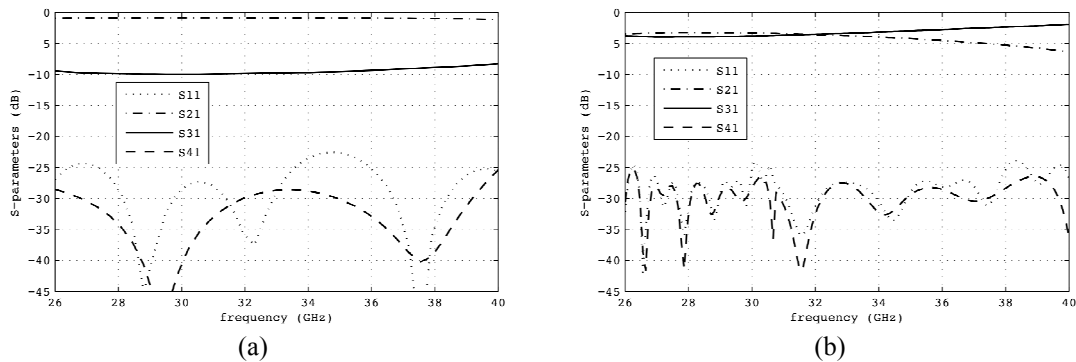


Figure 4. SIW E-plane couplers with pairs of circular apertures; performance of 10dB coupler (a), performance of 3dB coupler (b).

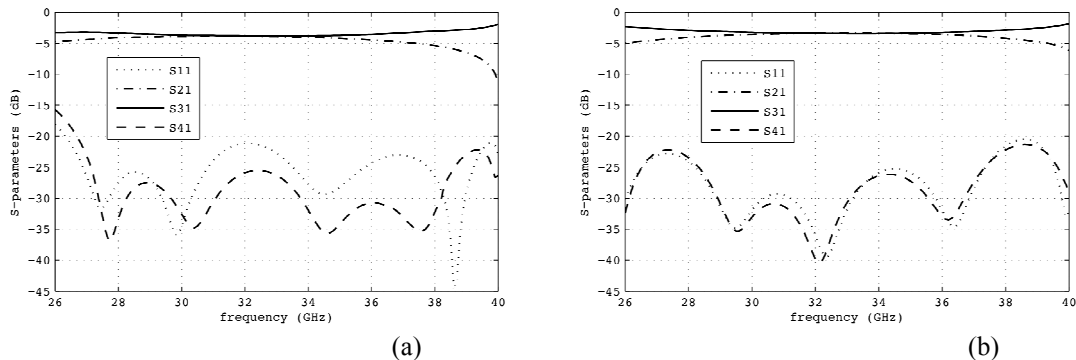


Figure 5. Six-section (a) and eight-section (b) E-plane 3dB Riblet-Saad couplers in SIW technology according to Fig.1(a); all-dielectric waveguide interface ports included at all ports.