Design of Multilayered Substrate-Integrated Waveguide Cross-Slot Couplers

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***Abstract*— This paper introduces multilayered cross-guide cross-slot directional coupler designs in substrate-integrated waveguide (SIW) technology. Interface ports are modeled by dielectric-filled waveguides which allow for a higher dynamic range in scattering parameters than conventionally used microstrip-to-SIW transitions. It is demonstrated that in double- or triple-layered configurations, coupling values between 10 dB and 25 dB can be achieved over almost an entire waveguide band. Several Ka-band double- or triple-layered cross-guide coupler designs are presented using an Ansoft's HFSS design environment. CST's Microwave Studio is used for performance verification**

I. Introduction

The crossed-slot waveguide directional coupler (also referred to as Moreno cross-guide coupler) is well known for its broadband performance in feed systems and integrated waveguide technology, e.g., [1], [2]. Its initial design is facilitated by simple guidelines [3], and more recently, optimization within electromagnetic analysis tools has been used to refine performance specifications, e.g. [4], [5].

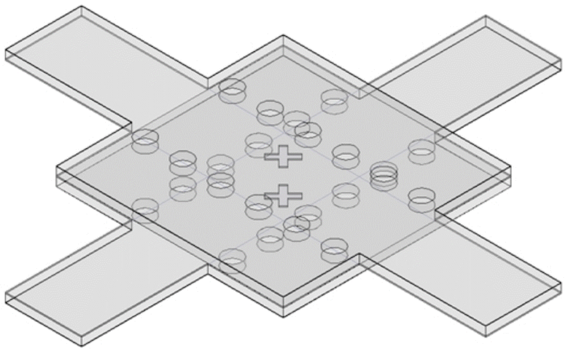
Substrate-integrated waveguide (SIW) technology [6] has established itself as a feasible compromise between microstrip circuitry and all-metal waveguide components. Therefore, many waveguide-based design principles and procedures find renewed applications in SIW research. Due to its planar fabrication approach, H-plane waveguide components have mostly been implemented in SIW, e.g. [7], [8]. However, in view of increasing system integration, e.g., [9], SIW components and subsystems will have to be designed to also include waveguide E-plane technology.

Only few attempts have been focused on designing E-plane SIW components. They include E-plane directional couplers with circular apertures [10], [11] and Riblet-Saad couplers [11].

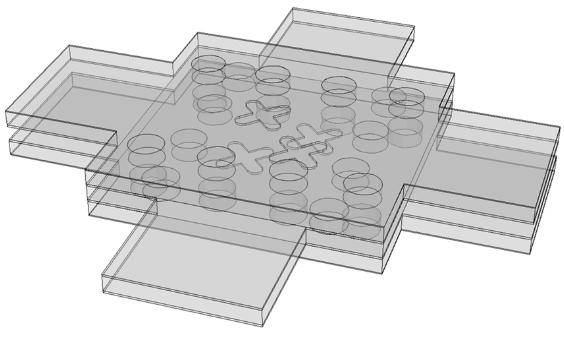
Therefore, this paper focuses on the design of cross-guide couplers in SIW technology. Besides the standard two-layer configurations known from standard waveguide technology, also six-port triple-layered designs are presented.

II. Modelling and Design

Fig. 1a and Fig. 1b show the double- and triple-layered cross-guide couplers, respectively, in SIW technology. Note that all-dielectric waveguide ports are used as interfaces. This has proven to be more reliable since the conventionally used microstrip-to-SIW transitions are too reflective to reliably evaluate a SIW structure with scattering parameter values below approximately 15 to 20 dB. For a detailed discussion on this topic, the reader is referred to [11].



(a)



(b)

Fig. 1 Double-layered (a) and triple-layered (b) cross-guide SIW couplers with all-dielectric waveguide ports

Fig. 2 shows the top view indicating the relevant dimensions of the designs presented in this paper.

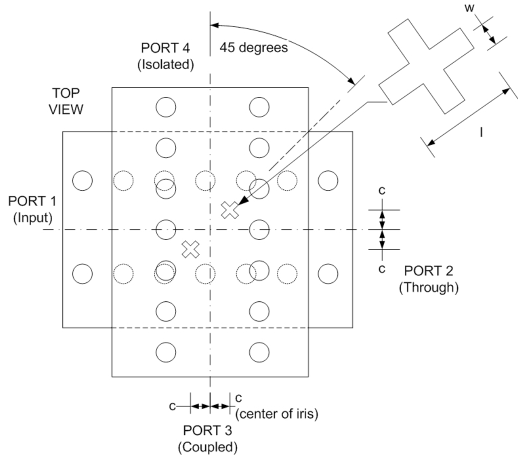
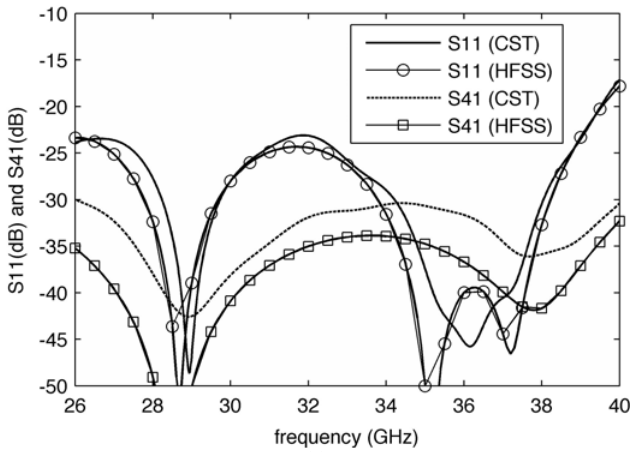


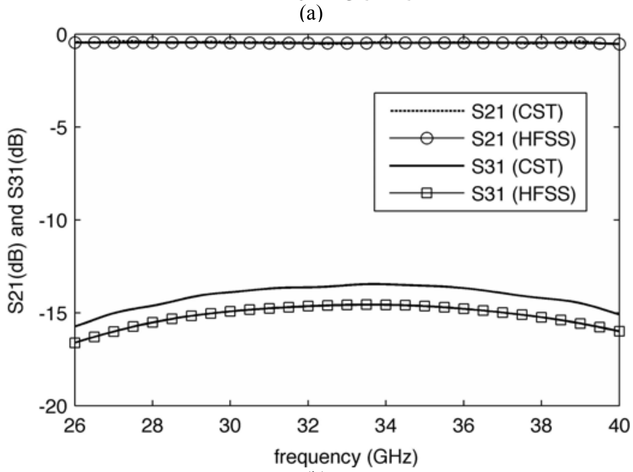
Fig. 2 Top view of cross-guide SIW coupler and related dimensions

All multilayered cross-guide SIW directional couplers are designed for Ka-band (26-40 GHz) operation. The SIW parameters are: Rogers RT duroid/5880 substrate with ε_r=2.2 and height b=508µm; via-hole diameter d=1.19mm, centre-to-centre via spacing p=2.38mm; centre-to-centre via waveguide width a=5.52mm; copper thickness t=35µm so that the air-filled coupling crosses have a thickness of 2t=70µm; the centres of the crosses are determined by their quarter-wavelength distance (at midband frequency) and determine their locations c in Fig. 2. For a given coupling value, the dimensions of the coupling crosses (w, l) are modified by fine optimization in an HFSS environment. Initial cross-slot polarisability parameters can also be obtained by using closed-form expressions [12].

In order to verify the results obtained with HFSS, a 15dB coupler is analysed by both HFSS and CST (Microwave Studio). The results are compared in Fig. 3 and demonstrate very good general agreement. The only differences are in the S parameters referring to the isolated (S_{41}) and coupled (S_{31}) ports. The differences in S_{11} and S_{41} are acceptable since they mainly occur below -30dB. The through port performance (S_{21}) shows excellent agreement. The results at the coupled port (S_{31}) differ by about 1dB. The slot dimensions are specified in Table I.



(a)



(b)

Fig. 3 Comparison of results obtained by HFSS and CST at the example of a 15 dB double-layered cross-guide SIW coupler; (a) reflection and isolation; (b) coupling and through; cf. Table I for slot dimensions

TABLE I
SLOT LENGTHS FOR COUPLERS SHOWN IN FIG. 3 AND FIG. 4

Figure	Coupling (dB)	Slot length l (mm)
4a	6	2.70
4b	10	2.20
3a, 3b	15	1.70
4c	20	1.45

III. RESULTS

Fig. 4 shows the performances of double-layer cross-guide SIW couplers designed for 6 dB, 10 dB and 20 dB.

The only additional parameters, which are have not been specified in the previous section, are the slot locations and their dimensions. For the couplers shown in Fig. 3 and Fig. 4, parameters c and w (c.f. Fig. 2) have been kept constant at c=1.1mm and w=0.4mm. The slot lengths are listed in Table I.

The coupling performances of the 10dB (Fig. 4b) and 20dB coupler (Fig. 4c) are acceptable for wideband specifications. The 6dB coupler in Fig. 4a has, of course, the largest cross-slot dimensions and, therefore, shows a higher dependence on frequency, especially at higher frequencies, as is known from E-plane waveguide aperture couplers.

Fig. 5 shows the performances of three cross-slot directional coupler designs in a triple-layered arrangement according to Fig. 1b. Compared to the double-layered designs in Fig. 3 and Fig. 4, the cross-slot location and width have been changed to c=1.27mm and w=0.13mm. The lot lengths are given in Table II.

TABLE II
SLOT LENGTHS FOR COUPLERS SHOWN IN FIG. 5

Figure	Coupling (dB)	Slot length l (mm)
5a	15	2.03
5b	20	1.73
5c	25	1.70

known from regular metallic waveguide E-plane couplers, e.g. [13], the coupler performs more consistently and over a wider bandwidth as the coupling weakens. However, multilayered SIW couplers provide significantly smaller component size and are much better suited for integration with printed-circuit fabrication techniques.

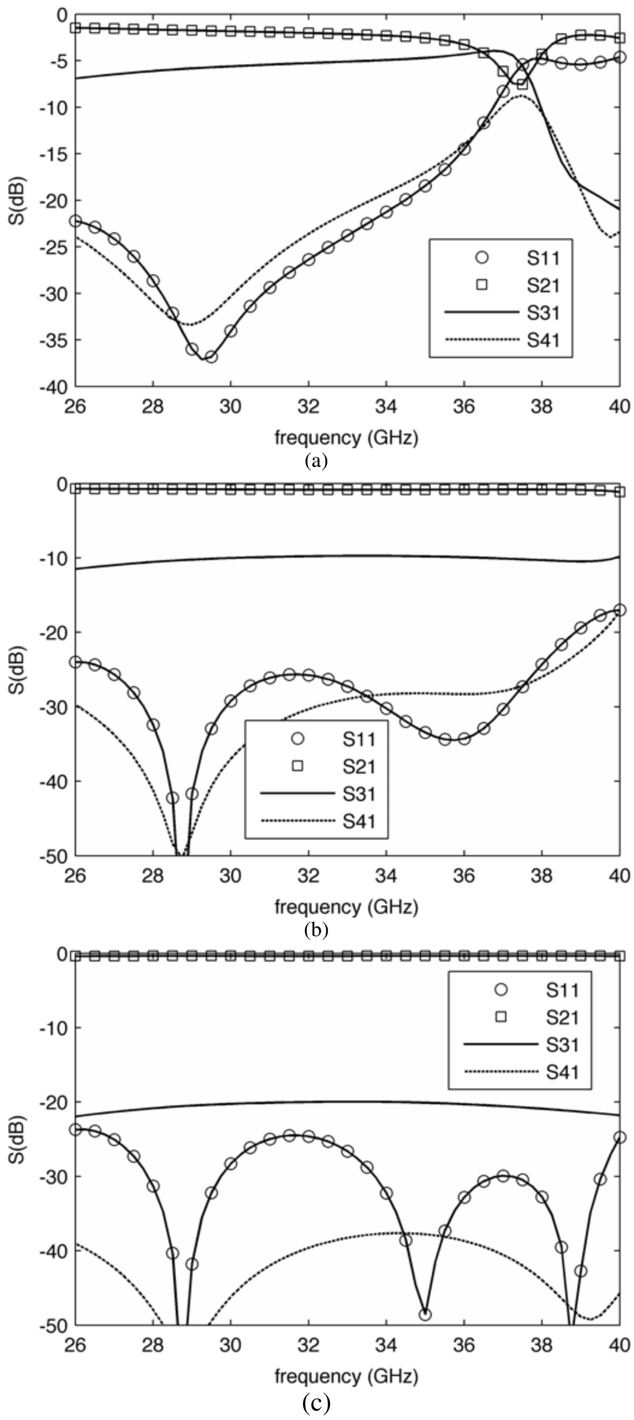


Fig. 4 Performances of double-layered cross-guide SIW couplers designed for 6dB (a), 10dB (b) and 20dB (c); cf. Table I for slot dimensions

The triple-layered structures are fed through an input port in the centre layer which couples the same amount of power to the top and bottom layers (S_{31} and S_{51}, respectively, in Fig. 5). Note that isolation parameters S_{41} and S_{61} should theoretically be identical. They commonly differ slightly due to numerical inaccuracies below -30 or -40 dB. The coupler performances are generally good, extending over a wide range of the Ka-band. Limitations appear at the higher frequency spectrum where coupling decreases and return loss increases. As is

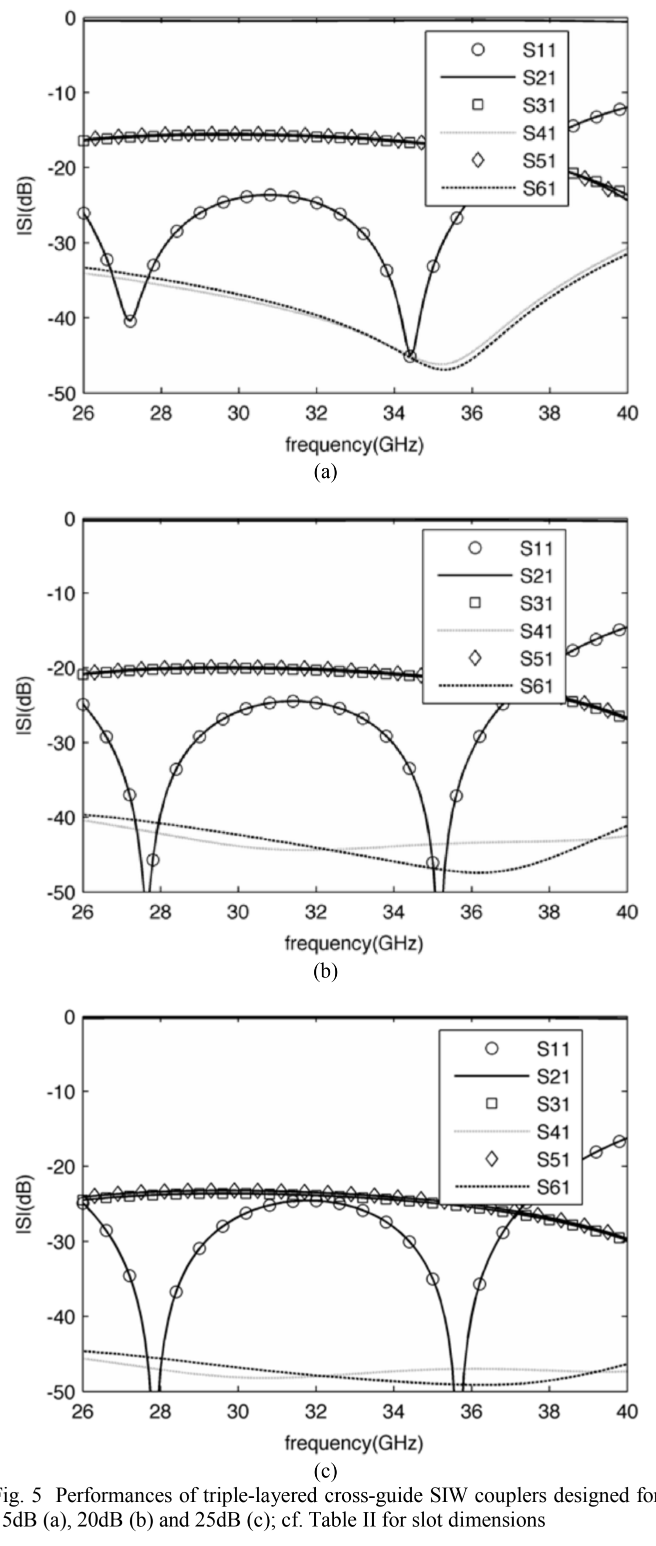


Fig. 5 Performances of triple-layered cross-guide SIW couplers designed for 15dB (a), 20dB (b) and 25dB (c); cf. Table II for slot dimensions

IV. CONCLUSIONS

Multilayered cross-slot cross-guide directional couplers present a viable option for implementation in SIW applications. It is demonstrated that double-layered designs with coupling values of 10 dB or higher can achieve almost constant performance over an entire waveguide band. The dependence on frequency increases (the bandwidth decreases) for tighter coupling specifications. Triple-layered structures of comparable coupling values perform well over a slightly reduced bandwidth, but excellent performance can still be achieved over more than 70 percent of a waveguide band. A comparison between results obtained with HFSS and CST shows good agreement and thus validates the designs presented in this paper. Note that all structural parameters are specified so that they are available for implementation, verification and performance refinement.

ACKNOWLEDGMENT

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