Design of Ka-Band Substrate Integrated Waveguide Bend, Power Divider and Circulator

Bouchra Rahali, Mohammed Feham, Junwu Tao

Abstract— ***Substrate Integrated Waveguide (SIW) features interesting characteristics for the design of microwave and millimeter-wave integrated circuits. In this study, a substrate integrated waveguide bend, power divider and circulator are conceived and optimized in Ka- band by Ansoft HFSS code. Thus, through this modeling, design considerations and results are discussed and presented. Compact size and planar form make these devices structure easily integrated in planar circuits.***

Keywords—Rectangular waveguide; microwave components; SIW; bend;power divider; circulator; HFSS.

I. INTRODUCTION

The substrate integrated waveguide technology [1] is based on realizing a waveguide within a dielectric substrate. The upper and lower substrate metallization are used as the broad walls of the waveguide structure while the side narrow walls are synthesized in the form of two rows of metalized via-holes. Most microwave components were modeled in SIW technology such as bends [2], filters [3], couplers [4], duplexers [5], sixports [6], circulators [7] and phase shifter [8]. In this paper,Ka-band RSIW components as bend,power divider and coupler are designed.

II. FUNDAMENTAL RSIW CHARACTERISTICS

Starting from a dielectric substrate between two metal planes, two rows of holes are drilled and metalized, making contact between the two metal planes of the substrate. The diameter d of holes stems, p the spacing between the holes and W_{SIW} spacing between the two rows of holes are physical parameters necessary for designing rectangular wave guide in technology SIW (RSIW) (Figure 1).

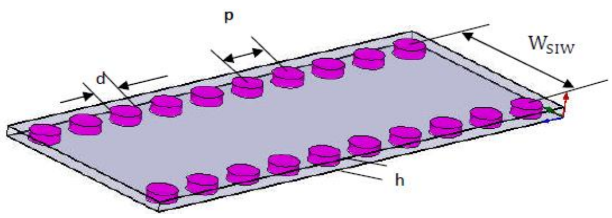


Figure 1: rectangular wave guide integrated into a substrate RSIW

(Figures 2 and 3) show RSIW and equivalent rectangular waveguide giving the same characteristics of the fundamental mode propagation.

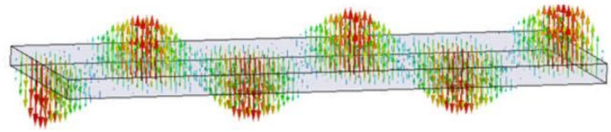


Figure 2: Electric field of TE_{10} mode rectangular waveguide equivalent, W_{eq}=4.795mm, h=0.508mm, $\varepsilon_r = 2.2$ at frequency f = 33GHz

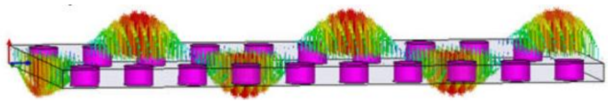
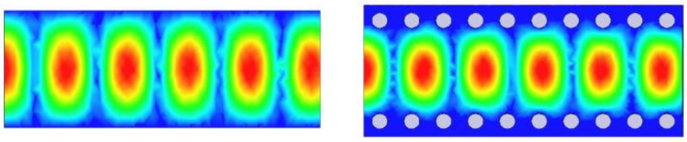


Figure 3: electric field of TE_{10} mode of RSIW, W_{SIW}=5.237mm, h=0.508mm, p=1.6mm, d=0.8mm,$\varepsilon_r = 2.2$ at frequency f = 33GHz

From a conventional waveguide [2][3][4] WR28 filled dielectric permittivity ε_r=2.2, tanδ=0.0009, height h = 0.508mm, RSIW components Table I designed in Ka-band [26.5-40] GHz are analyzed showing in Figure 4 and 5 the similarity of the electromagnetic field distribution of TE_{10} mode and the dispersion characteristics by using the finite element method (FEM) “HFSS” [11].

Table I

Classic wave guide	Equivalent wave guide	RSIW
WR28 ε_r =1 a=7.112mm,b=3.556mm	h=0.508mm, ε_r = 2.2 W_{eq}= 4.795mm	h=0.508mm,ε_r =2.2, d=0.8mm, p=1.6mm W_{SIW} =5.237mm



(a) (b)

Figure 4: Electric field distribution of the TE_{10} mode in the equivalent rectangular waveguide (a) and RSIW (b) at the frequency f = 33GHz

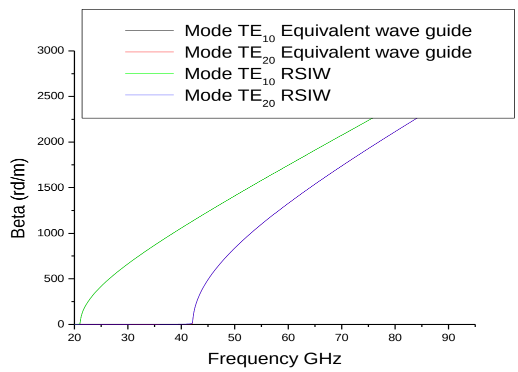


Figure 5: Dispersion characteristics

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III. STUDY OF TRANSITION TAPER

Being a 3-D structure, a substrate integrated waveguide cannot be directly connected to traditional planar circuits. Therefore, several efficient transition sections have been investigated. In our study, we are interested in microstrip-to-waveguide coplanar transition proposed [12], and proved to be very efficient and wideband.

The coplanar microstrip-to-waveguide transition is essentially a tapered microstrip line connecting a microstrip of width W_{mst}, to the waveguide of width W_T, as shown in Fig. 6.

Since W_{mst} is usually fixed for a microstrip line of a certain characteristic impedance, the two main design parameters are W_T (transition width) and L_T (transition length) [12][13]. The design of this type of transition is mostly realized by optimizing the feature sizes while monitoring the HFSS software [11] Table II. Figures 7 and 8 show the results of analysis RSIW without transition and with a coplanar taper of dimensions L_T and W_T.

Table II

L_T	**1.473mm**
W_T	1.651mm
W_{mst}	0.838mm
L	16mm

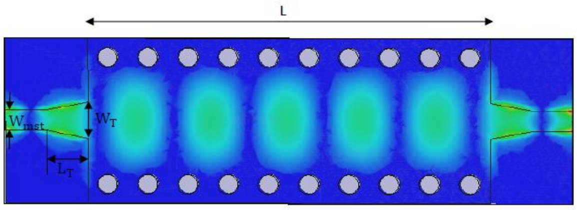

Figure 6: Electric field distribution of TE_{10} mode at f = 33 GHz in the matched RSIW

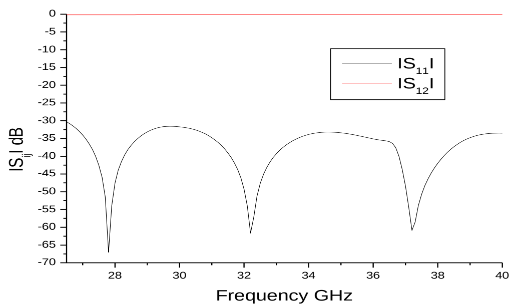

Figure 7: Transmission coefficients S_{21} and reflection S_{11} of the RSIW

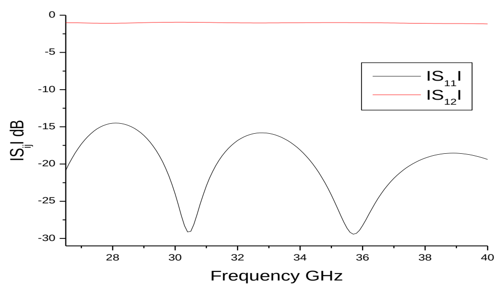

Figure 8: Transmission coefficients S_{21} and reflection S_{11} of RSIW with taper

They also show that S_{11} is less than-15dB over 33.13% of the frequency band and the transmission coefficient S_{12} is around -0.94dB over the entire band.

This concept [12] allows the design of a completely integrated planar circuit of microstrip and waveguide on the same substrate without any mechanical assembly [13] [10].

IV. DESIGN OF RSIW PASSIVE DEVICES

A. Chamfered right bend

The propagation direction is not always straight, to change this direction stiffness waveguides requires the use of bends, and they are essentials in microwave systems such as radars, diplexers and multiplexers. The common method to compensate the discontinuity of right bend in waveguide is to chamfrain [2][10] its corner in order to reduce the reflection. Through this paper, we are interested in the design of RSIW chamfered bends in the Ka-band. Thus, we have analyzed the effect of position of the chamfrain on the transmission coefficient bends. We have analyzed many structures with HFSS tool, such as the right bend Figure 9 and a rectangular chamfered bend with a chamfrain such that Aopt $=W_{SIW}$ [10] Figure 10, Aopt is the distance between the middle of the chamfrain and the inner corner of the right bend. Figures 9 to 12, illustrating the electric field distribution of the fundamental mode TE_{10} , the transmission coefficient S_{21} and the reflection coefficients S_{11} also confirm [2]that the optimum position of the chamfer is Aopt = W_{SIW} to the right bend designed in RSIW technology in the frequency band [26.5-40] GHz.

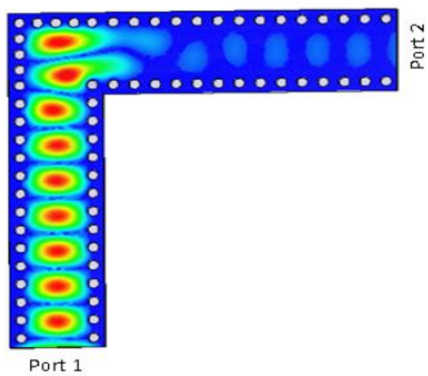

Figure 9: Simulation of the TE_{10} electric field magnitude of a right bend at f=40GHz

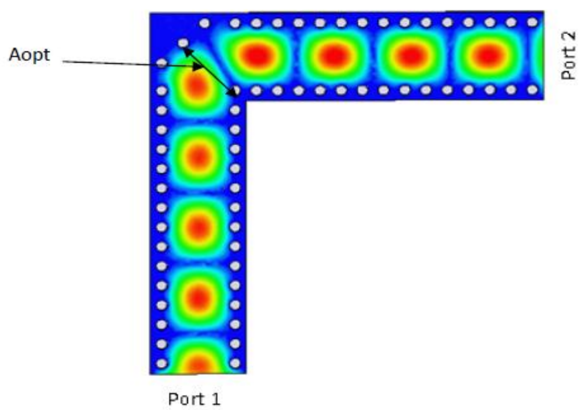

Figure 10: Plot of the TE_{10} electric field magnitude of a RSIW chamfered bend Aopt=W_{SIW} at f=28GHz

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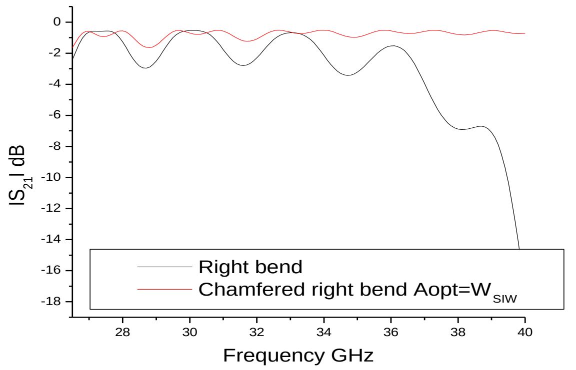

Figure 11: Comparing transmission coefficient S_{21}

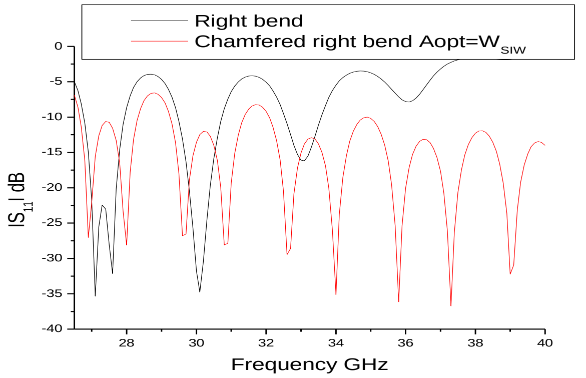

Figure 12: Comparing reflexion coefficient S_{11}

The analysis of the compensation of the discontinuity of a right bend in RSIW shows that the ideal and optimal position of the chamfrain is obtained with Aopt $=W_{SIW}$. It is found that is very important to maintain a uniform width W_{SIW} along the bend to obtain efficient signal transmission.

B. Power divider

The three ports power dividers [4][5][6][7] are mainly two types T and Y [10], with equal power division ratio where the half power (-3dB) of an input signal is provided to each of the two output ports.

The analyzed power divider Figure 13, designed in the Ka-band with the characteristic parameters reported in table I and II.

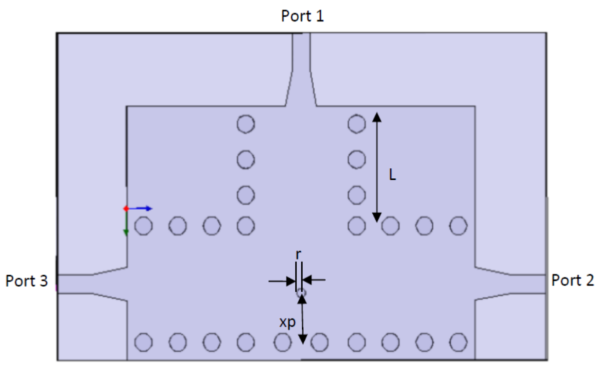

Figure 13: RSIW power divider

Figures 14 and 15 respectively illustrate the distribution of the electric field of the TE_{10} mode in the band [26.5-40] GHz and transmission coefficients S_{21}, S_{31} and reflection coefficient S_{11} of the power divider RSIW designed based cylindrical metal rods of diameter d.

The figure 15 indicates that S_{11} is less than -15 dB between 26.5GHz and 38.19 GHz which is more than 36.15 % of the bandwidth. The optimal values of the inductive cylinder are r = 0.2mm, xp=0.4mm. Transmission coefficients S_{21} and S_{31} fluctuate between-3.71dB and -4.02dB being very acceptable levels.

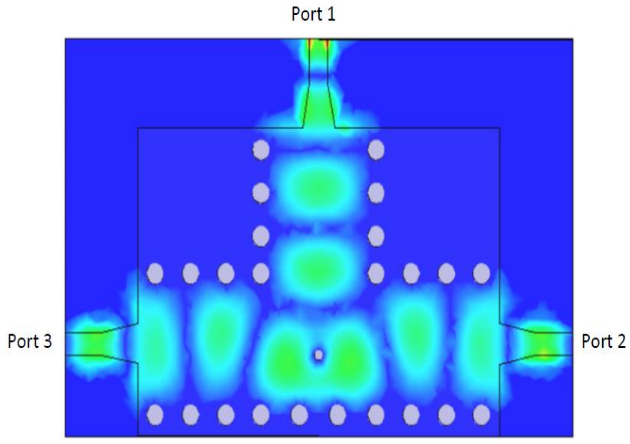

Figure 14: Electric field distribution of the TE_{10} mode at f = 31.5GHz in the power divider with inductive cylinder

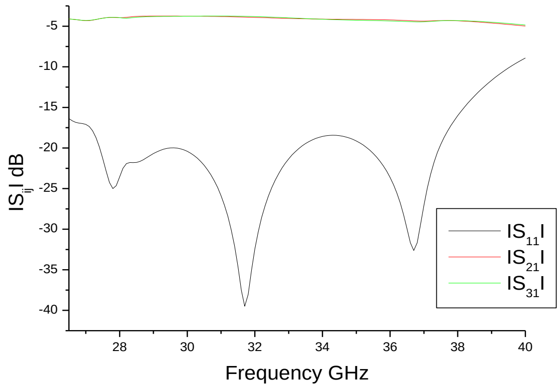

Figure 15: Parameters S_{ij} in the power divider with inductive cylinder

C. Circulator

The circulator waveguide technology [4][5][6][7] Figure 16 can be used in many applications in telecommunications. This circulator was designed by using cylindrical metal rods, with the same parameters presented in tables I and II, L = 9.6mm R_f=0.9mm h_f=0.508mm.

The RSIW circulator model in Figure 16 has been simulated by Ansoft HFSS [11]. Figure 17 illustrates the distribution of the electric field of the TE_{10} mode circulator RSIW in the Ka band. The frequency response of RSIW circulator, transmission coefficients S_{21}, reflection coefficients S_{11} and isolation coefficients S_{31} are reported through the Figure 18. Analysis of the results of this study shows that the reflection loss S_{11} below-15dB occupy more than 6.5% of the bandwidth against by the insertion loss S_{21} is in the range of -1.2dB , while the maximum of the isolation S_{31} is -41.6dB. At frequency of 33.7 GHz, the two figures 17 and 18 confirm traffic property of the device [10].

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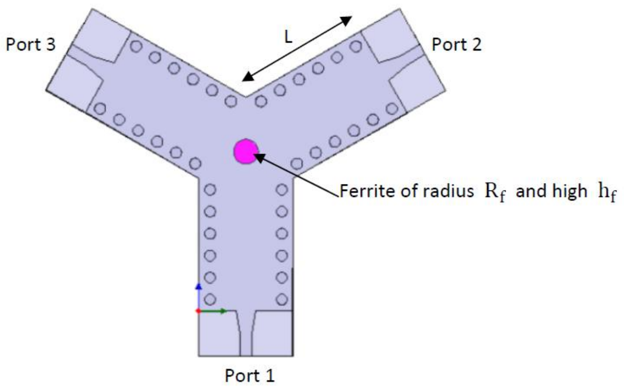

Figure 16 : RSIW circulator

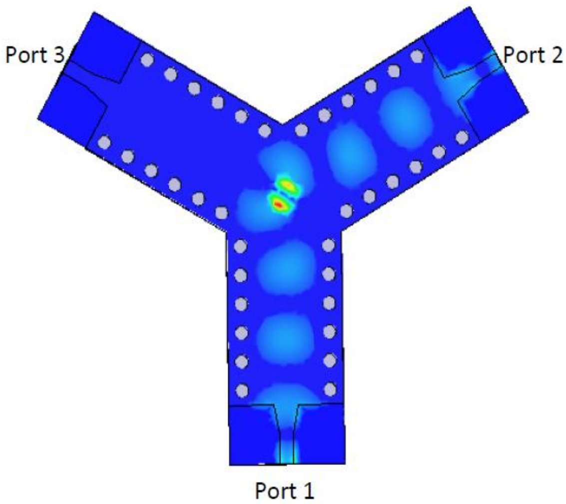

Figure 17 : Electric field distribution of the TE_{10} mode of the RSIW circulator at f = 33.7 GHz

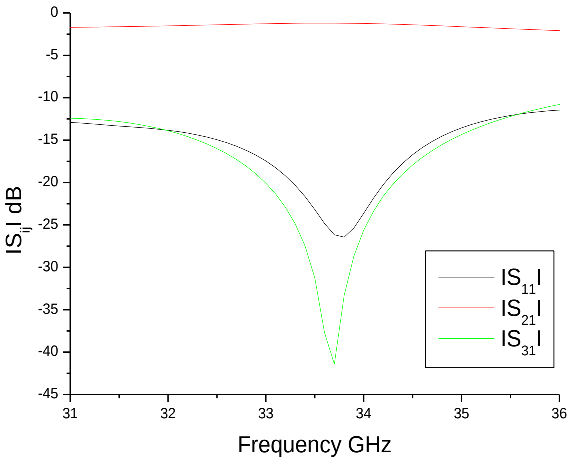

Figure 18: Parameters S_{ij} of RSIW circulator

V. CONCLUSION

To design three passive components based on RSIW in a Ka- band we have presented a simple and fast method using Ansoft HFSS code. The developed RSIW bend, power dividers and circulator, are used in complex microwave and millimeter wave circuits. The simulation results have shown the good performance of these RSIW structures.

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