SUBSTRATE INTEGRATED WAVEGUIDE POWER DIVIDER, CIRCULATOR AND COUPLER IN [10-15] GHZ BAND

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ABSTRACT

The Substrate Integrated Waveguide (SIW) technology is an attractive approach for the design of high performance microwave and millimeter wave components, as it combines the advantages of planar technology, such as low fabrication costs, with the low loss inherent to the waveguide solution. In this study, a substrate integrated waveguide power divider, circulator and coupler are conceived and optimized in [10-15] GHz band by Ansoft HFSS code. Thus, results of this modeling are presented, discussed and allow to integrate these devices in planar circuits.

KEYWORDS

Rectangular waveguide, Microwave components, SIW, Power divider, Circulator, Coupler, HFSS.

1. INTRODUCTION

SIW technology [1][2] is interesting for the benefits of rectangular waveguides while maintaining in planar profiles. Easy integration and a high quality factor are interesting characteristics of the rectangular waveguide in the technology SIW (RSIW). A large range of SIW components such as bends [3], filters [4], couplers [5], duplexers [6], sixports [7], circulators [8] and phase shifters [9] has been studied. Figure 1 illustrate the RSIW which is designed from two rows of periodic metallic posts connected to higher and lower planes mass of dielectric substrate. Figure 2 and 3 shows the similarity of the geometry and the distribution of the electric field between (RSIW) and the equivalent rectangular wave guide [2] [3]. In this paper, [10-15] GHz band RSIW components are proposed and optimized. They are essential for many microwave and millimeter-wave integrated circuits and telecommunication systems.

2. FUNDAMENTAL RSIW CHARACTERISTICS

For designing (RSIW) (Figure 1) many physical parameters are necessary as d the diameter of holes stems, p the spacing between the holes and W_{SIW} spacing between the two rows of holes. Two rows of holes are drilled and metalized, making contact between the two metal planes of the dielectric substrate, permitting propagation for all modes TE_{n0} [5]. The lines of current along the lateral walls of the RSIW are vertical, the fundamental TE_{10} mode may be propagated. Electrical performance of RSIW and a conventional rectangular waveguide filled with dielectric of width W_{eq} [4] are similar.

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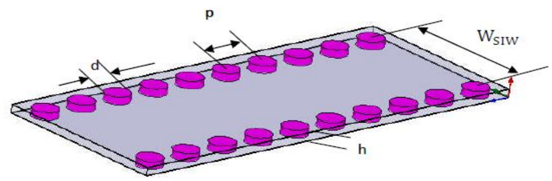

Figure 1. Rectangular wave guide integrated into a substrate RSIW

For obtaining the same characteristics of the fundamental mode propagating in the RSIW (Figure 2) having the same height and the same dielectric, empirical equations [2] were derived in order to determine the width of the equivalent rectangular wave guide

$$W_{eq} = W_{SIW} - \frac{d^2}{0.95\,p} \qquad (1)$$

$$p < \frac{\lambda_0}{2}\sqrt{\varepsilon_r} \qquad (2)$$

$$p < 4\,d \qquad (3)$$

$$\lambda_0 = \frac{c}{f}$$

Where λ_0 is the space wavelength.

Period p must be low for reducing leakage losses between adjoining cylinders. We examined through this study, the RSIW [10-15] GHz from a conventional waveguide [10], the feature parameters are outlined in Table 1. Taking the same approach, cited above [2], we deduce the parameters of RSIW and the equivalent waveguide (Figure 2) Table 1.

Table 1

Classic wave guide	Equivalent wave guide	RSIW
WR75 a=18.35mm, b=9.175mm, ε_r=1	h=0.8mm, ε_r=2.2 W_{eq}=10.73mm	h=0.8mm, ε_r=2.2,d=0.5mm,p=1mm, W_{SIW}=11mm

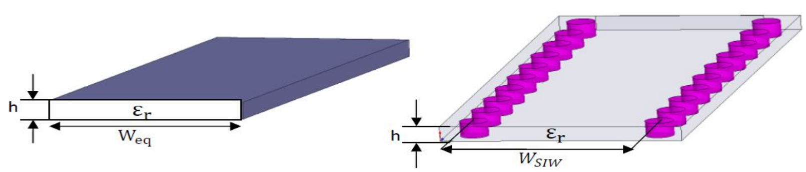

Figure 2. Equivalent rectangular waveguide and RSIW

Formulas given by equations (1), (2) and (3) are commonly used to get initial values W_{SIW}, optimized by HFSS tool [11] based on the finite element method (FEM) .It has enabled the layout of the cartography of the electromagnetic field of the TE_{10} mode and scatter diagram.

Electromagnetic field distribution of TE_{10} mode guided in the guide RSIW and its equivalent in waveguide technology are similar (Figure 3).

(a) (b)

Figure 3. Electric field distribution of the TE_{10} mode in the equivalent rectangular waveguide (a) and RSIW (b) at the frequency f = 12 GHz

Figure 4 illustrate the coherence of the dispersion characteristics between these two waveguides . It is worth noting that the similarity of propagation is valid for all modes TE_{n0}.

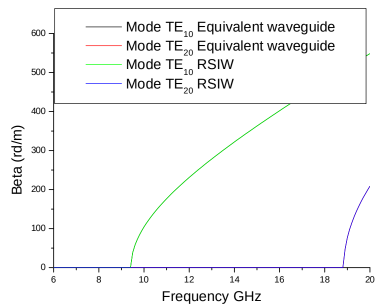

Figure 4. Dispersion characteristics

2. RSIW-MICROSTRIP TAPERED TRANSITION

For interconnect RSIW to the planar transmission lines the microstrip transition taper [12] is employed .A tapered section is used to match the impedance between a 50 Ω microstrip line in which the dominant mode is quasi-TEM and TE_{10} mode of the RSIW, their electric field distributions are approximate in the profile of the structure.

From several formulas given [13] initial parameters W_T and L_T are determined and optimized with HFSS [11] Table 2. Figure 5 shows the proposed configuration of two back-to-back transitions of microstrip line to RSIW. The results of the RSIW analysis without transition and with a coplanar taper of dimensions L_T and W_T are mentioned in Figures 6 and 7.

Table 2

L_T	2.1mm
W_T	3.81mm
W_{mst}	2.41mm
L	40.016mm

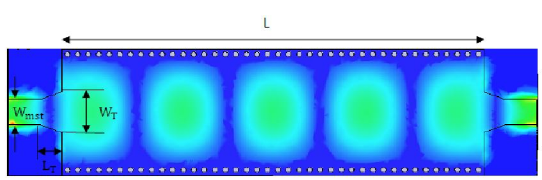

Figure 5. Electric field distribution of TE_{10} mode at f = 12 GHz in the matched RSIW

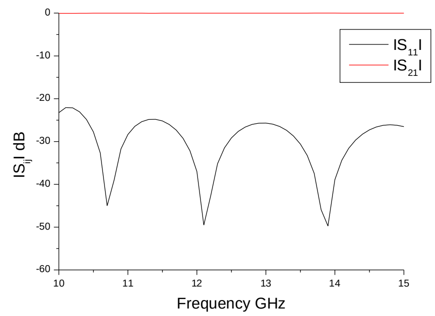

Figure 6. Transmission coefficients S_{21} and reflection S_{11} of the RSIW

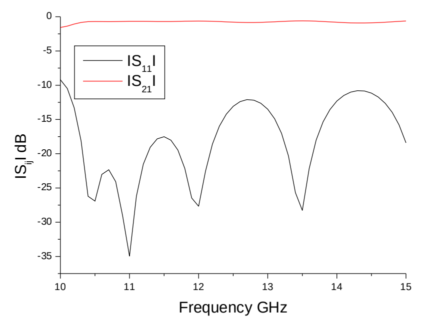

Figure 7. Transmission coefficients S_{21} and reflection S_{11}
of the matched RSIW with taper

Through the figure 7 we see that the reflection coefficient S_{11} remains below -15 dB over 18.8% of the frequency band and the transmission coefficient S_{21} is around - 0.63 dB across the entire band. On the same substrate and without any mechanical assembly [14] [15] ,this transition [13] allows the conception of a completely integrated planar circuit .

3. Design of RSIW passive devices

3.1. SIW Power divider

Power dividers [16] are required in many applications. There are separated in two types T and Y [14] [15], which are commonly used to deliver copies of a signal in a system. This application focuses on the three ports power dividers with equal power division ratio where the half power (-3 dB) of an input signal is provided to each of the two output ports. The S matrix for a three ports network, is shown in equation (4)

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \qquad (4)$$

With the characteristic parameters reported in table 1 and 2, we analyzed power divider (Figure 8), designed in the [10-15] GHz band and based on three identical RSIW connected to form a T with L=14.5mm. An inductive metal cylinder of radius r and position xp is added to this junction in order to minimize reflection losses at the input port. To achieve reflection losses, below -15dB, reach acceptable limit it is generally useful to fix the radius r to the corresponding available practical value of diameter drills, and then change xp. Then, a microstrip transition is added to each port so that we can integrate this component directly into a microstrip circuit. The input wave (port 1) is divided into two parts which output to port 2 and port 3, respectively. For this purpose,

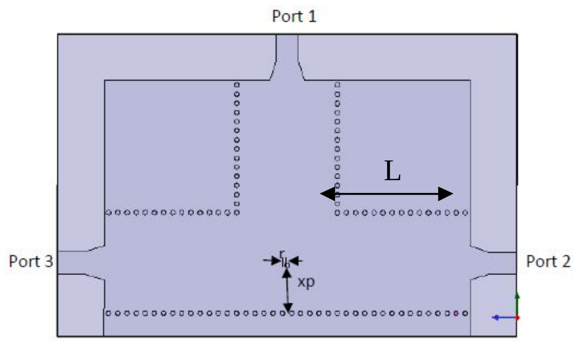

Figure 8. RSIW power divider

Through Figures 9 and 10 we see respectively the distribution of the electric field of the TE_{10} mode in the band [10-15] GHz and transmission coefficients S_{21}, S_{31} and reflection coefficient S_{11} of the power divider RSIW .

The figure 10 indicates that S_{11} is less than -15 dB between 10.87 GHz and 12.44 GHz which is more than 17.3 % of the bandwidth. The optimal values of the inductive cylinder are r =0.254mm, xp=5.25mm. Transmission coefficients S_{21} and S_{31} fluctuate between -3.17 dB and - 3.34 dB being very acceptable levels.

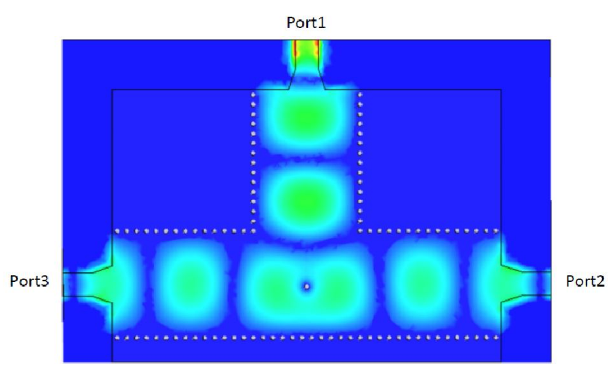

Figure 9. Electric field distribution of the TE_{10} mode
at f = 12 GHz in the RSIW power divider with inductive cylinder

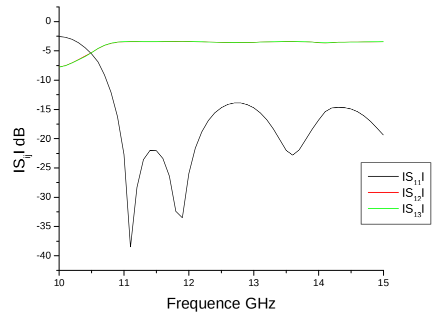

Figure 10. Parameters S_{ij} in the RSIW power divider with inductive cylinder

2.2. SIW Circulator

Several types of solutions are common and recommended to provide protection microwave sources. However, in high power, the circulator waveguide technology [8] is still the best solution. Its topology of a hexapole (Figure 11) having three access separate of 120° from each other, around a central body of ferrite (nickel materials and lithium ferrite) [8] [9] , to which is applied a vertical magnetic field conferring to the circulator the property of non-reciprocity.

Indeed, incoming wave from port 1, 2 or 3 cannot out by the access 2, 3 or 1, respectively.
Its ideal matrix [S] would be as follows:

$$[S] = \begin{bmatrix} 0 & 0 & e^{j\varphi} \\ e^{j\varphi} & 0 & 0 \\ 0 & e^{j\varphi} & 0 \end{bmatrix} \quad (5)$$

φ is the phase shift corresponding to transmission of the access signal to the next access. The non-reciprocity of the device shown by the non-symmetry of the matrix [S] is the main point explaining that this function can be used in many applications in telecommunications. With the same parameters presented in Tables 1and 2, L = 9.016mm this circulator was designed Figure 11.

In this paper the saturation magnetization of ferrite material is [9] $4\pi Ms$ = 1250 Gauss. Its relative dielectric constant is 13.7 and a radius R_f calculated by [8].

$$R_f = \frac{1.84\,c}{\omega_0 \sqrt{\varepsilon_f}} \quad (6)$$

Where c and ω_0 are respectively the velocity of light in the free space and the operation frequency [7]. The ferrite radius and height are R_f=2.3mm h_f=0.8mm.

In the band [10-15] GHz Figure 12 illustrates the distribution of the electric field of the TE_{10} mode in RSIW circulator. Through Figure 13 the frequency response of RSIW circulator, transmission coefficients S_{21}, reflection coefficients S_{11} and isolation coefficients S_{31} are reported. Analysis of the results of this study shows that the reflection loss S_{11} below-15dB occupy more than 10.75% of the bandwidth against by the insertion loss S_{21} is in the range of -0.43 dB , while the maximum of the isolation S_{31} is -43.85 dB. At frequency of 12.5 GHz, the two figures 12 and 13 confirm the property of the circulation component [10].

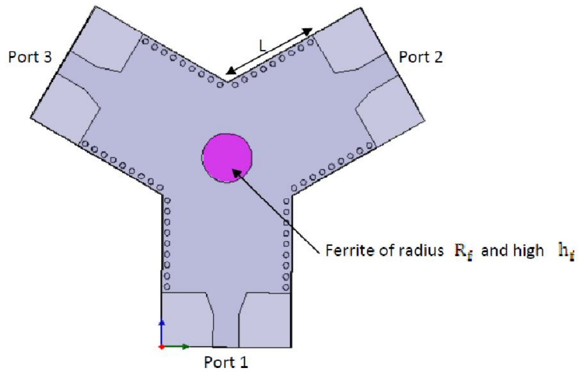

Figure 11. RSIW circulator

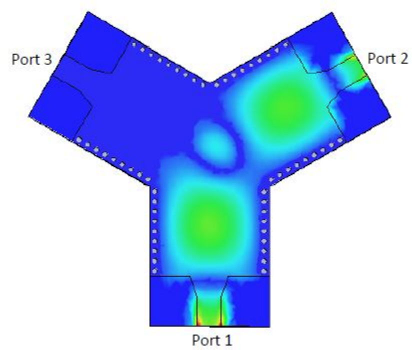

Figure 12. Electric field distribution of the TE_{10} mode of the RSIW circulator at f = 12.5 GHz

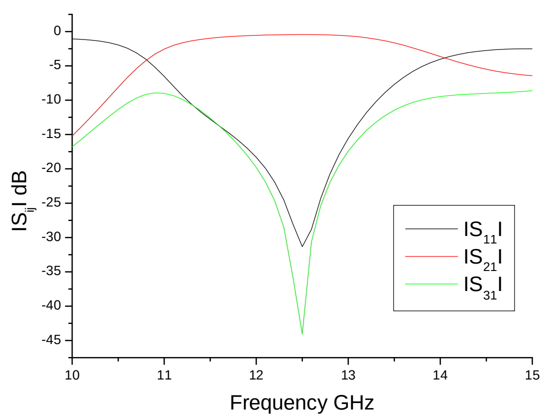

Figure 13. Parameters S_{ij} of RSIW circulator

2.2. SIW Coupler

The directional couplers [5] which have been widely used as key components in many systems have been intensively studied used for routing, dividing and combining the signals in the microwave system. The RSIW directional couplers [5] [17] are extensively investigated Figure 14. The RSIW directional coupler (-3dB) is conceived by two RSIW with a common wall on which an aperture realize the coupling between these two guides. This coupler was designed by using metal rods of square section [18] with the same parameters presented in tables 1 and II. The geometry of the coupler is determined [15][19] based on an even/odd mode analysis, where the even mode is the TE_{10} and the odd mode is the TE_{20}. The phase difference $\Delta\varphi$ between the two modes is expressed by

$$\Delta\varphi = (\beta_1 - \beta_2) W_{ap} \tag{7}$$

Where β_1 and β_2 are the propagation constants of the TE_{10} and TE_{20} modes, respectively. In the band of operation, the condition $\Delta\varphi = \pi/2$ needs to be satisfied. To each port the tapered transition is added so that we can integrate this component directly into a microstrip circuit. The matrix [S] of a symmetric coupler (-3 dB), adapted to its access, is given by equation (8).

$$[S] = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 1 & j & 0 \\ 1 & 0 & 0 & j \\ j & 0 & 0 & 1 \\ 0 & j & 1 & 0 \end{bmatrix} \tag{8}$$

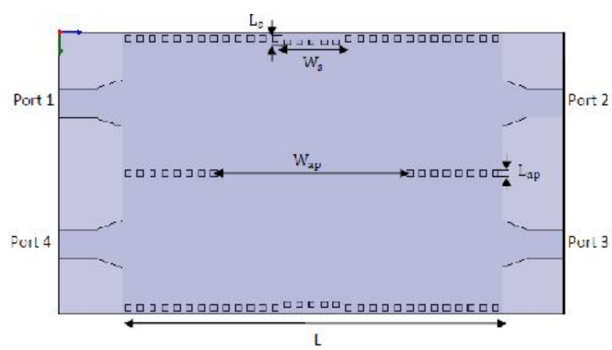

Figure 14. RSIW coupler

To achieve wide-band performance the coupler parameters are optimized using simulation under HFSS [11]. The final dimensions of the RSIW coupler are presented in Table 3.

Table 3

L	31.016mm
W_s	6mm
L_s	0.3mm
W_{ap}	16mm
L_{ap}	0.5mm

In the [10-15] GHz band Figures 15 and 16 present electric field distribution of TE_{10} mode and the reflection coefficients S_{11}, the transmission coefficients S_{21}, the coupling coefficient $S_{31}$and the isolation coefficient S_{41}. We have the levels of reflection and isolation below -15 dB with more than 20.34% of the bandwidth, and which the insertion loss S_{21} and coupling S_{31} are of theorder of -3.09 ± 0.7 dB. These results show clearly the directional coupler character in the [10-15] GHz band.

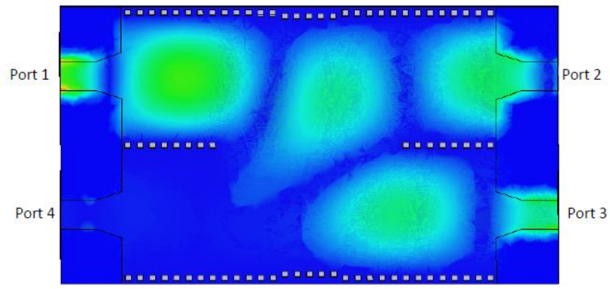

Figure 15. Electric field distribution of TE_{10} mode for RSIW coupler at f=12 GHz

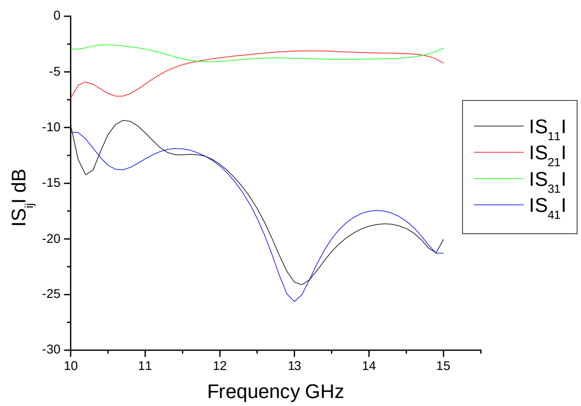

Figure 16. Frequency response of the RSIW directional coupler

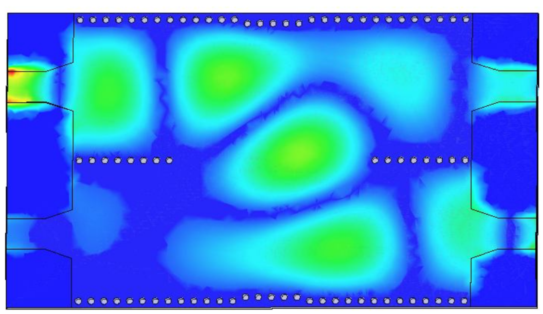

Figure 17. Electric field distribution of TE_{10} mode for RSIW coupler at f=12 GHz

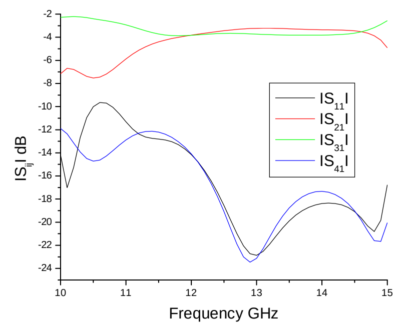

Figure 18. Frequency response of the RSIW directional coupler

3. CONCLUSIONS

In this paper, we have investigated a [10-15] GHz band substrate integrated waveguide passive components. Using Ansoft HFSS code we have designed three passive components based on RSIW components. Firstly, the RSIW three ports power dividers where half the power of an input signal is provided to each of the two output ports. Secondly, the RSIW circulator has been designed; it can be integrated on the same substrate with microstrip and other planar circuit. The HFSS code has also been applied to the conception and analysis of the RSIW coupler .The RSIW power dividers, circulator and coupler can be used as essential components in the conception of planer microwave and millimeter wave circuits. Through the results we see the good performance of these integrated devices conceived in a [10-15] GHz band.

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