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Substrate integrated waveguide (SIW) 3 dB coupler for K-Band applications

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Abstract. This paper presented a designed coupler by using Rogers RO4003C with thickness (h) 0.508 mm and relative permittivity (ε_r) 3.55. The four port network coupler operates in K-band (18-27 GHz) and design by using substrate integrated waveguide (SIW) method. The reflection coefficient and isolation coefficient of propose Substrate Integrated Waveguide (SIW) coupler is below than -10 dB. Meanwhile the coupler requirements are phase shift 90^o between coupled port and output. SIW are high performance broadband interconnects with excellent immunity to electromagnetic interference and suitable for use in microwave and communication electronics, as well as increase bandwidth systems. The designs of coupler are investigated using CST Microwave Studio simulation tool. This proposed couplers are varied from parameters that cover the frequency range (21 -24 GHz) and better performance of scattering (S-parameter).

1 Introduction

At this moment in time, rectangular waveguide components are used in communication and microwave system, radar with outstanding features such as increase power capability and small insertion loss [1]. However, it is in bulky size that strict and limits the accuracy and precision in manufacturing. Unfortunately, Printed Circuit Board (PCB) is sensitive toward about radiation by others active and passive devices in the same dielectric substrate [2] [3].

Substrate Integrated Waveguide (SIW) is a techniques can achieve a little loss in the highest frequency that can come up with very good frequency performance on low dielectric permittivity substrate materials compared to coplanar waveguide (CPW) and planar circuits in microstrip [4] [5]. The development of Substrate Integrated Waveguide (SIW) methods build-up from double rows of conducting via (slots) filled in a dielectric substrate to connect two plates (copper planes) of substrate [6][7]. The advantages of Substrate Integrated Waveguide (SIW) technology are to miniaturize size and minimization losses [3]. The technology is widely applied to the implementation of Microwave field [8]. Moreover, one of emerging topics in communication application is the Internet of Things (IoTs).

Coupler is a passive device which couples with generating the transmission power with properties requirements such as operational bandwidth, frequencies, and size [9]. Moreover, coupler may have 3-port or 4-port components which denoted as input, through (transmitted), coupled and isolated [10]. The coupling of mechanism divided into two which depends on the interspacing between them, and the coupled line.

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In this paper, a Substrate Integrated Waveguide (SIW) coupler for microwave and communication are proposed. The operating frequency for the coupler investigated from 18 GHz to 27 GHz. Simulate performance results are show in this research paper.

2 Design Descriptions

2.1 Configuration of Substrate Integrated Waveguide (SIW) Coupler

Basic structure of coupler is shown in Fig. 1 below with parameters.

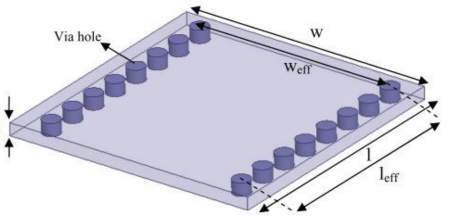

Fig. 1. Structure of Substrate Integrated Waveguide (SIW) [9].

As depicted in Fig. 1, the structure Substrate Integrated Waveguide (SIW) consists of two rows of circular metallic via holes which immersed in dielectric substrate. Moreover, there is also effective width (W_{eff}) and effective length (L_{eff}) of Substrate Integrated

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Waveguide (SIW) cavity can be calculated from Equation (1) and (2) [8] :

$$W_{eff} = w - \frac{d^2}{0.95p} \qquad (1)$$

$$L_{eff} = l - \frac{d^2}{0.95p} \qquad (2)$$

Where: *w* and *l* are the width and length of Substrate Integrated Waveguide (SIW) cavity.

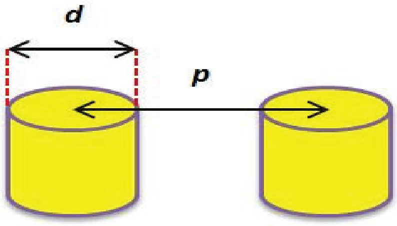

Fig. 2. The Structure of Circular Metallic Via

From Fig. 2, to minimize the leakage between metallic via holes, the pitch distance between circular metallic via (*p*) needs to be reduced and the diameter of circular metallic via holes (*d*) needs to be considered. The practical of *d/p* ratio value needs to follow 0.5<*d/p*<0.8 are specified. To determine the diameter (*d*) and pitch (*p*) expression (3), (4) and (5) is used [6]:

$$d < \frac{\lambda_g}{5} \qquad (3)$$

$$p \leq 2d \qquad (4)$$

$$\lambda_g = \frac{2\pi}{\sqrt{\frac{\varepsilon_r (2\pi f)^2}{c^2} - (\frac{\pi}{w})^2}} \qquad (5)$$

Where f is the frequency and c is the speed of light.

3 Design Techniques

The proposed design of coupler is designed on Roger 4003 substrate materials where copper layers on both planes. The size of coupler is 25 mm x 15 mm which is considered as compact size. The design of Substrate Integrated Waveguide (SIW) coupler is shown in Fig. 3.

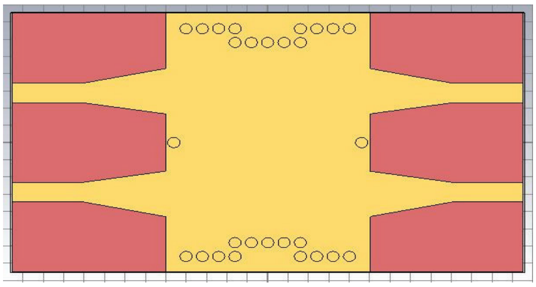

Fig. 4. Substrate Integrated Waveguide (SIW) Coupler in CST

Fig. 4 illustrates the proposed coupler using Substrate Integrated Waveguide (SIW) techniques. In this section, there are 13 metallic via holes on both side wall of substrate and 2 metallic via holes at the centre. Coupler using this technique needs to build transition tapered proposed to match impedance between Substrate Integrated Waveguide (SIW) and 50 Ohm microstrip. Thus, it increases the insertion loss in proposed design.

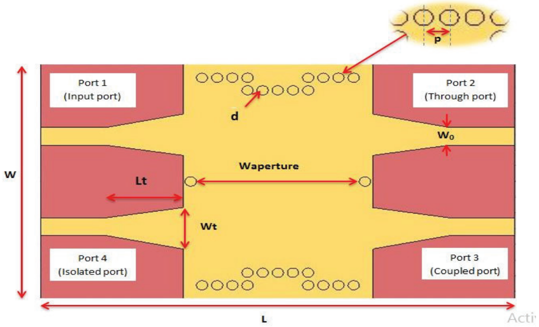

Fig. 5. The physical dimensions of Substrate Integrated Waveguide (SIW) Coupler

Table 1. Dimensions of Coupler

Parameters	Descriptions	Dimensions (mm)
L	The length of substrate	25.00
W	The width of substrate	15.00
d	Diameter of circular via	0.40,0.50,0.60,0.85
p	Pitch of circular via	0.80
Wt	Width of microstrip taper	2.63
Lt	Length of microstrip taper	4.00
$W_{aperture}$	Width of aperture	9.20
W_{siw}	Width of siw	6.60
W_o	Width of microstrip line	1.15

4 Analysis of Previous Research

As depicted in Fig. 6 the paper presented a design and fabrication of X-band Substrate Integrated Waveguide (SIW) directional coupler. From above table, the overall size of design is 54 mm x 48 mm at operating frequency 8 to 10.5 GHz. The results show the flat coupling only at narrow bandwidth with 7.97%. For measurement result, there are high amplitude imbalances [7].

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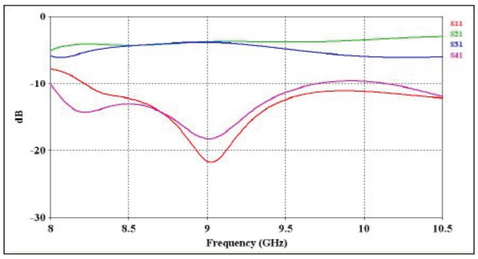

Fig. 6. Simulated Results S-Parameter

The paper that reviewed in fig. 7 is design of broadband planar Substrate Integrated Waveguide (SIW) Transvar coupler. The size of coupler is 80 mm x 60 mm. From the table, the insertion loss is higher below than -5dB although flat coupling is achieved. Then, the simulated and measured result are quiet similar in insertion loss performance [10].

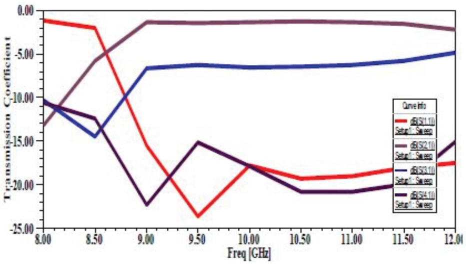

Fig. 7. Simulated Results S-Parameter

5 Results and Discussions

5.1 Parametric Study for Substrate Integrated Waveguide (SIW) coupler

This parameter such as Waperture, Metallic via holes and pitch between holes with rectangular waveguide structure is studied to start the initial design of proposed Substrate Integrated Waveguide (SIW) coupler. This section was discussed about the modification of coupler based on the diameter of circular metallic via (*d*). The variable diameter (*d*) is varied from 0.4 mm, 0.5 mm, 0.6 mm and 0.85 mm.

5.1.1 The Simulated Reflection Coefficient (S_{11})

The results illustrated with Fig. 8, indicate that the return loss (S_{11}) better than 10 dB. The simulation results show the investigated in variable diameter which are 0.4 mm, 0.5 mm, 0.6 mm and 0.85 mm have a good performance on return loss (S_{11}). It is less than -30 dB and the better return loss (S_{11}) with -66.676 dB but there are shifting in frequency is occurred to diameter 0.85 mm. All the proposed coupler is operating in K-Band (18-27 GHz). Therefore, the diameter of circular metallic via is affecting the return loss of waveguide.

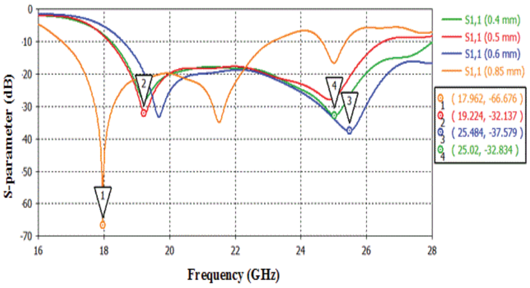

Fig. 8. Simulated result of Reflection Coefficient (S_{11})

5.1.2 The Simulated Isolation Coefficient (S_{41})

As depicted in Fig. 9, the isolation coefficient (S_{41}) presented a good performance are lower than -28 dB for all optimization diameter of circular metallic via (*d*). Moreover, as can be seen In Fig. 9 below, the better isolation response is at -44.46 dB compared to the other variable diameters (*d*). The simulations results highlight, the coupling between port 1 (input) and port 3 (coupled) became weak, S_{11} and S_{41} are increases.

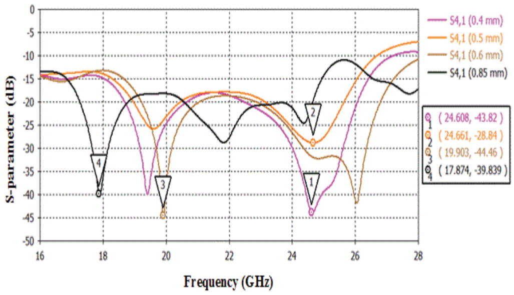

Fig. 9. Simulated result of Isolation Coefficient (S_{41})

5.1.3 The Simulated Phase Difference (S_{31}-S_{21})

From Fig. 10 shows a coupler with d=0.4 mm shows the S_{21} and S_{31} are close to -4.005 dB (22 GHz) and to -3.3242 dB (21.99 GHz). The phase difference in fig. 11 is nearly 90^o from 19.0 GHz to 26.0 GHz.

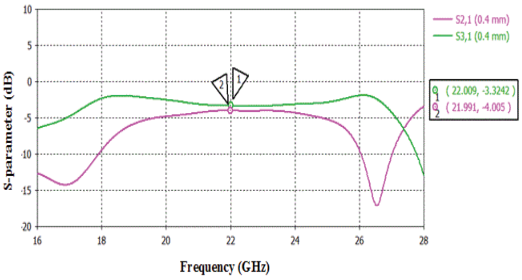

Fig. 10. Simulated S_{21} and S_{31} (d=0.4 mm)

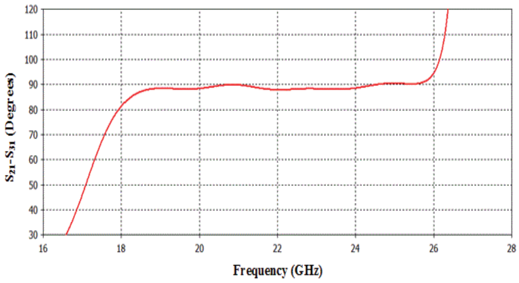

Fig. 11. Simulated phase of coupled S_{21} and S_{31} (d=0.4 mm)

Simulation parameters in Fig. 12 are shown the value S_{21} and S_{31} are closely to -3.5025 dB and -3.6317 dB at 22.0 GHz. The phase difference is close to 90^o from 18.0 GHz to 26.0 GHz are presented in Fig. 13 respectively.

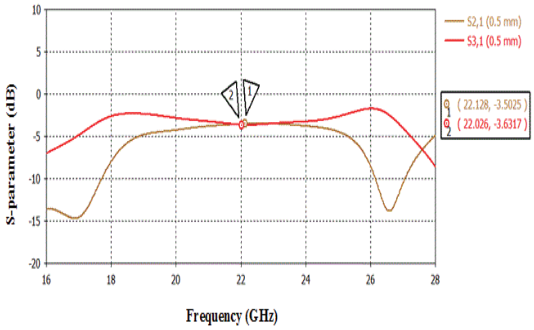

Fig. 12. Simulated S_{21} and S_{31} (d=0.5 mm)

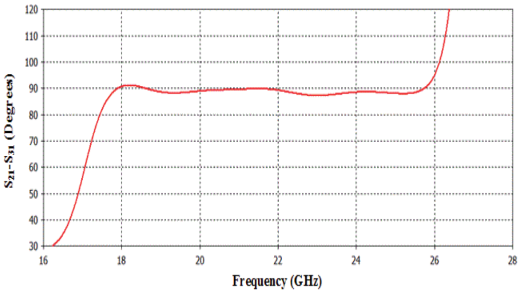

Fig. 13. Simulated phase of coupled S_{21} and S_{31} (d=0.5 mm)

The phase difference in Fig. 14 and Fig. 15 illustrates that approximately 90^o which is are the simulated S_{21} and S_{31} shown close to -3.7907 dB and -3.341 dB at 0.6 mm. The frequency covered in 19.0 GHz to 26.0 GHz.

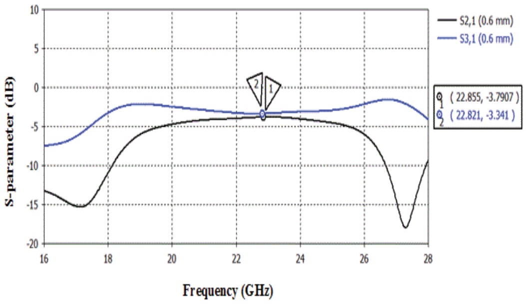

Fig. 14. Simulated S_{21} and S_{31} (d=0.6 mm)

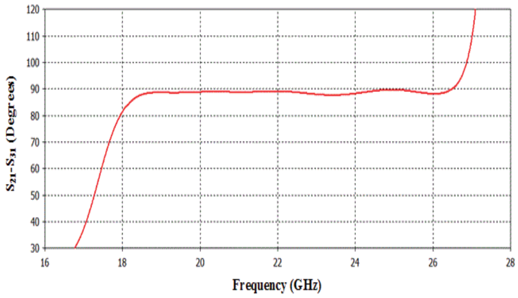

Fig. 15. Simulated phase of coupled S_{21} and S_{31} (d=0.6 mm)

In Fig. 16, their S_{21} and S_{31} at d=0.85 mm are near to -4.5932 dB and -3.1409 dB. The phase difference (S_{21} – S_{31}) at diameter 0.85 mm is varying from 3^o and nearly 90^o from 16.0 GHz to 22.0 GHz in Fig. 17.

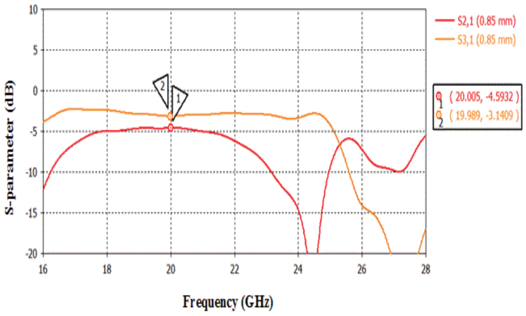

Fig. 16. Simulated S_{21} and S_{31} (d=0.85 mm)

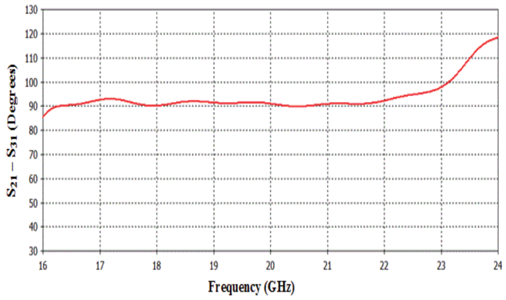

Fig. 17. Simulated phase of coupled S_{21} and S_{31} (d=0.85 mm)

5.2 Final Results for Substrate Integrated Waveguide (SIW) coupler

From Fig. 18 shows the bandwidth is 11.93% with flat coupling between S_{21} and S_{31}. The Reflection coefficient and isolation performance are below -10 dB. Fig. 19 shows the phase difference is 90 degree at operating frequency 17.8 to 26 GHz. The dimension of coupler is 25 mm x 15 mm.

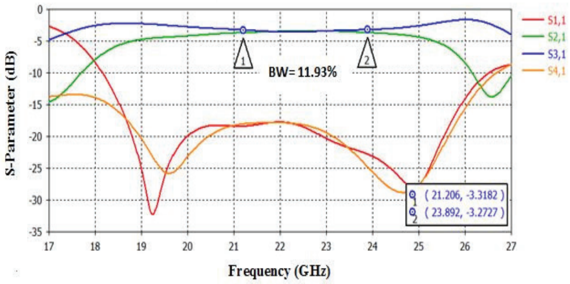

Fig. 18. Simulated Results S-Parameter (d=0.5 mm)

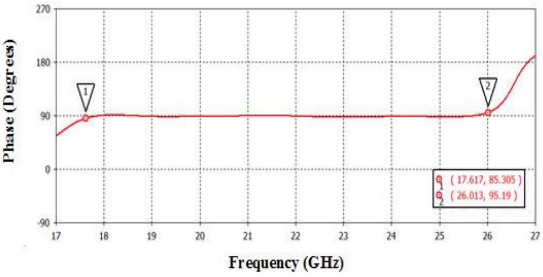

Fig. 19. Phase Difference (d=0.5 mm)

6 Conclusions

The variable diameters of circular metallic via are designed using CST software and the simulation performance are analysed. The design coupler is simulated using Computer Simulation Tools (CST) software. The parameter studies are designing on substrate material Rogers RO4003C, in the K-band has performed. The coupler with variable diameter of circular metallic via obtained a phase difference in 90^{o}. By using Substrate Integrated Waveguide (SIW) techniques the reduced in size and improved bandwidth (11.93%) of coupler is produced. These types of coupler are suitable and favourable choice for microwave applications.

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