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K-Band Substrate Integrated Waveguide (SIW) Coupler

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Abstract. This paper presents a designed coupler by using substrate Roger RO4003. The four port network coupler operates at (18-26 GHz) and designed by using substrate integrated waveguide (SIW) method. Substrate Integrated Waveguide (SIW) are high performance broadband interconnects with excellent immunity to electromagnetic interference and suitable in microwave and millimetre-wave electronics applications, as well as wideband systems. The designs of the coupler are investigated using CST Microwave Studio simulation tool. These proposed couplers are capable of covering the frequency range and provide better performance of scattering parameter (S-parameter). This technology is successfully approached for millimetre-wave and microwave applications. Designs and results are presented and discussed in this paper. The overall simulated percentage bandwidth of the proposed coupler is covered from 18 to 26 GHz with percentage bandwidth of 36.36%.

Index terms: *coupler, substrate integrated waveguide (SIW), using CST Microwave Studio simulation tool, millimetre-wave*

1. Introduction

Coupler is a passive device which couples for generating the transmission power with properties requirements such as operational bandwidth, frequencies, and size [1]. Communication services and wireless systems boost up with the presence of wideband coupler which is used to isolate the receiver port from the transmitters. The isolation in coupler is significant since poor isolation will result in reduced receiver sensitivity and higher DC offset in the system [1]. There are four available types of coupler which are directional, hybrid, rat-race and coupled line coupler. Each type of them exhibits different advantage [2]. In its basic configuration, a conventional coupler is formed by implementing multi-section approach. However, the conventional type has a narrow bandwidth which is lower than 25%, beside size of the coupler is large as well.

Recently, Substrate Integrated Waveguide (SIW) is a technology of an emerging method for the implementation of millimeter-wave and microwave field [4] such as the wireless base-stations satellites and the earth stations. These technologies consists of two layers of metal surfaces that covered both layers of substrate and the metallic via that connect two ground planes of substrate. Substrate Integrated Waveguide (SIW) is the highest frequency that can come up with very good frequency performance on low dielectric permittivity substrate materials [5]. This technology had already proven that structure of Substrate Integrated Waveguide relatively obtained less loss, high Q-factor waveguide in compact size and highly integrated structural [6-7]. The compact structure could reduce space and metal loss. There are many components that applied Substrate Integrated Substrate technique such as power divider [8], filters [7–10], antennas [7–9], and couplers [16]. In this paper, there are one (single-layer) coupler that proposed by using Printed Circuit Board (PCB) substrate materials which to evaluate the performance of coupler in terms of S-parameter in new square metallic via.

2. Design Descriptions

2.1 Configuration of coupler

The basic Structure for the coupler is shown in Figure 1. A directional coupler is a four-port network that is used to divide and distribute power. Moreover, coupler may have 3-port or 4-port components which denoted as input, through (transmitted), coupled and isolated [2]. The mechanisms of coupling are divided into two which depends on the interspacing between them, and the coupled line [3]. Directional coupler defines to operate an input so that the other output signals are functioning [1]. The basic concept of directional coupler is that the input power to port 1 (input) is coupling to port 3 (coupled) , meanwhile the remaining input power is to port 2 (through) and port 4 (isolated) which is where no power is delivered [1]. All port are matched there which means that the percentage of power entering Input port (port 1) is 100%. The 100% of power is equally divided into two, which is then transmitted to port 2 and port 3.

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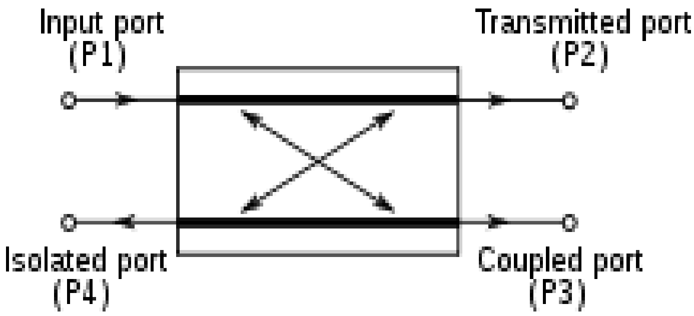

Figure 1. Basic Structure of Coupler

From Figure 1, The coupling value for S1,1 and S3,1=-3dB as shown in equation (1) below.

$$S_{21} = S_{31} = 10Log\frac{50}{100} = -3dB \tag{1}$$

The coupler is designed to have a good matching and isolation such that reflection and isolation is set to be less than 10% by using expression (2) below, so that all input power will be transmitted to the desired port only.

$$S_{11} = S_{41} = 10Log\frac{10}{100} = -10dB \tag{2}$$

2.2 Configuration of SIW Coupler

The basic configuration of K-Band Substrate Integrated Waveguide (SIW) coupler is shown in Figure 2 with parameters.

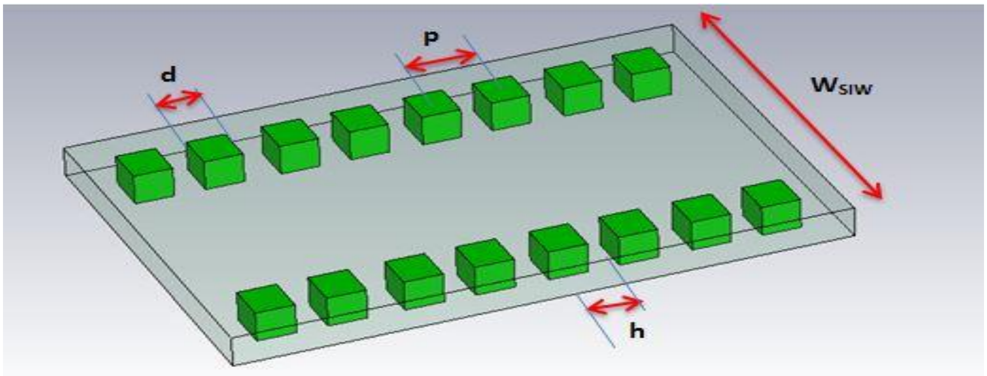

Figure 2. Basic Structure of Substrate Integrated Waveguide (SIW) [4-16]

Figure 2 shows the physical parameters that are important for designing the diameter of metal square holes (d) and the distance between adjacent via holes (p). Based on the Figure 1, distance between two rows of square holes (W_{siw}) and the thickness of substrate (h) are calculated by using equation [19].

$$Weq = Wsiw - \frac{d^2}{0.95p} \tag{3}$$

$$p < \frac{\lambda_0}{2}\sqrt{\varepsilon_r} \tag{4}$$

$$p < 4d \tag{5}$$

$$\lambda_0 = \frac{c}{f} \tag{6}$$

Where, λ_0 is the space wavelength.
The spacing between adjacent via holes (p) must be small to reduce the loss between metallic holes.

2.3 Microstrip Tapered Design

The microstrip is interconnected with the transmission lines by using tapered microstrip. By using tapered Transition the Substrate Integrated Waveguide (SIW) is to match the 50 Ω microstrip lines. The parameters involved are length of taper (L) and width of taper (W) [17–19]. Figure 3 shows the microstrip taper and the line model.

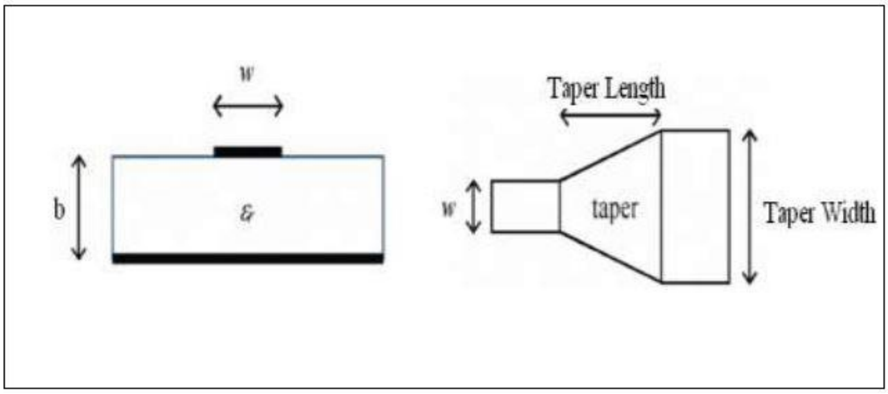

Figure 3. Microstrip taper and line model

Microstrip to waveguide transition is a tapered microstrip line connecting microstrip of width **'*w*'** to waveguide of width **'*Ag*'** as shown in Figure 3. Taper width **'*Wt*'** and taper length **'*Lt*'** are other two essential parameters for microstrip taper design. **'*Wt*'** and **'*Lt*'** can be determined by the relation given below from [20-21]:

$$\frac{W_t}{A_g} \approx 0.4 \tag{7}$$

$$(\frac{\lambda_g}{2}) < L_t < \lambda_g \tag{8}$$

Where,

$$\lambda_g = \lambda_c / \sqrt{\varepsilon_r} \tag{9}$$

$$L_t = \frac{n\lambda_g}{2}, n = 1,2,3,4... \tag{10}$$

3. Parameter Design of Substrate Integrated Waveguide (SIW) Coupler

The couplers are known as passive devices in microwave system which is applied for routing, dividing and combining the signals. By using equation from (4) and (5) the value of metallic via diameter and the distance between adjacent via were calculated. This coupler used a type of substrate Roger RO4003 with dielectric permittivity of substrate (ε_r) of 3.55, and thickness of 0.508 mm. The copper thickness of 0.035 mm with loss tangent of 0.0027 which is small means small signal loss making the substrate suitable for coupler design. Table 1 shows the values of parameters involved for the designed coupler. The microstrip transition is represented using tapered transition as shown in Figure 4.

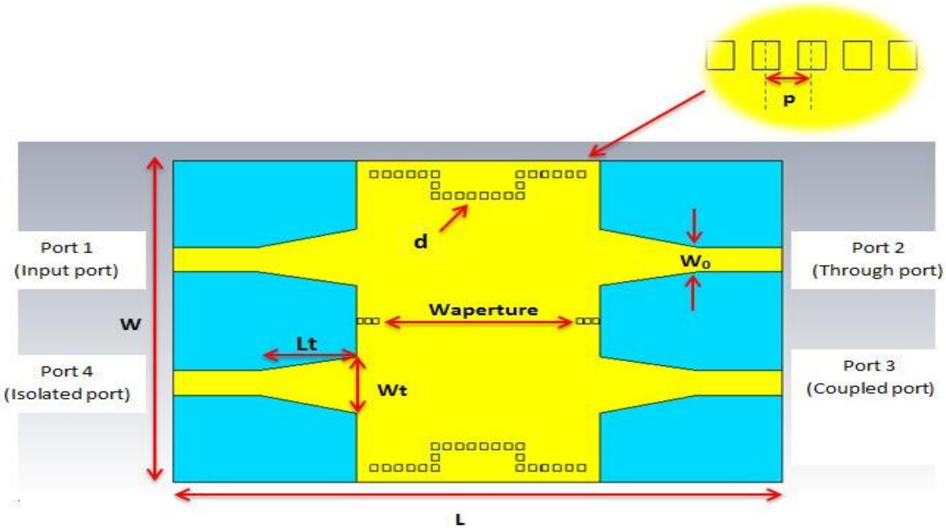

Figure 4. The configuration of coupler

Table I
The parameters for Substrate Integrated Waveguide (SIW) coupler

Parameters	Descriptions	Dimensions (mm)
L	Length of R04003 Substrate	25.00
W	Width of R04003 Substrate	15.00
d 1	Diameter of side wall square holes	0.40
d 2	Diameter of centre square holes	0.25
p	Distance between square holes	0.60
Wt	Width transition taper	2.63
Lt	Length transition taper	4.00
$W_{aperture}$	Width of aperture	8.52
W_{siw}	Width of siw	6.58
W_o	Width of microstrip TL	1.15

4. Results And Discussion

This section paper involves the analysis of coupler performance in terms of S-parameters such as reflected coefficient, isolation coefficient, bandwidth, E-field distribution and phase difference between S_{21} and S_{31} of the coupler. The K-Band Substrate Integrated Waveguide coupler is simulated by using CST software. The frequency obtained is from 18 GHz up to 26 GHz.

4.1 Simulation Result of S-Parameters vs Frequency

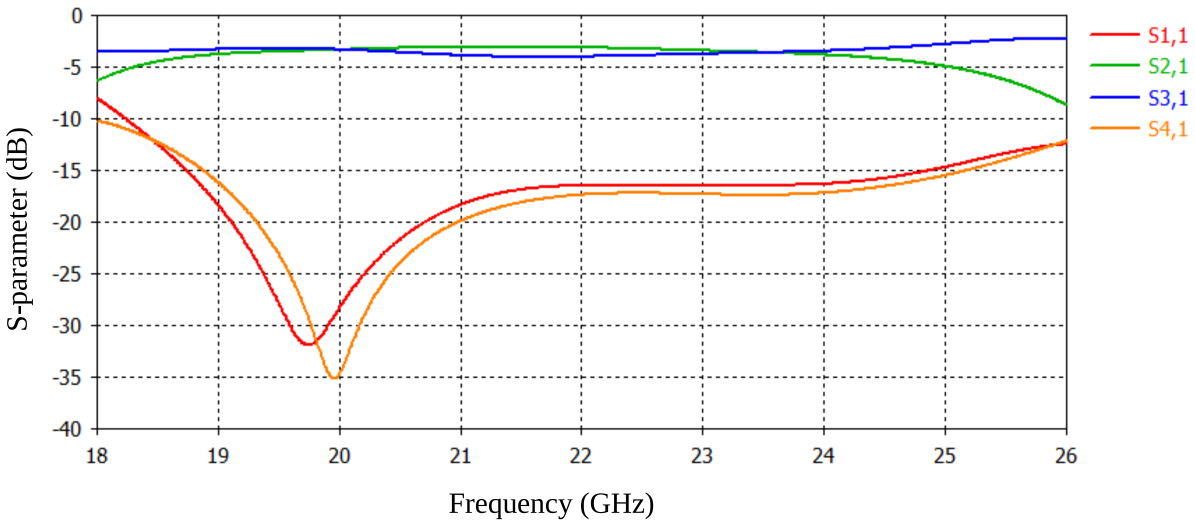

Figure 5. Simulated Result of SIW coupler

From Figure 5 the result analysis it shows the input port with reflection coefficient (S_{11}) of -28.13 dB. The isolation coefficient (S_{41}) value of simulation is -34.51 dB at frequency of 20 GHz. The output coupling port 2 and port 3 for insertion loss (S_{21}) and Coupling Coefficient (S_{31}) is are approximately -3.36 dB and -3.35 dB with the operating frequency of 18 GHz to 26 GHz. Therefore, S_{21} and S_{31} are in the range of best requirement results which are -3 ± 1.5 dB meanwhile S_{11} and S_{41} are less than -10 dB. The reflection and isolation are covering more than 36.36% of the bandwidth. By referring to Figure 5 based on this investigation of designed coupler, it is concluded that the coupling between port 1 and port 3 is affected by via and $W_{aperture}$.

4.2 E-Field Distribution of the Substrate Integrated Waveguide (SIW) coupler

Figure 6 shows the power that travel through the whole part of the coupler. The power flows from port 1 (input port) and coupled to port 3 (coupled port). The other input power goes to port 2 (through port). The design is in ideal condition because there are small amount of power that passed through ~~of~~ port 4 (isolated port).

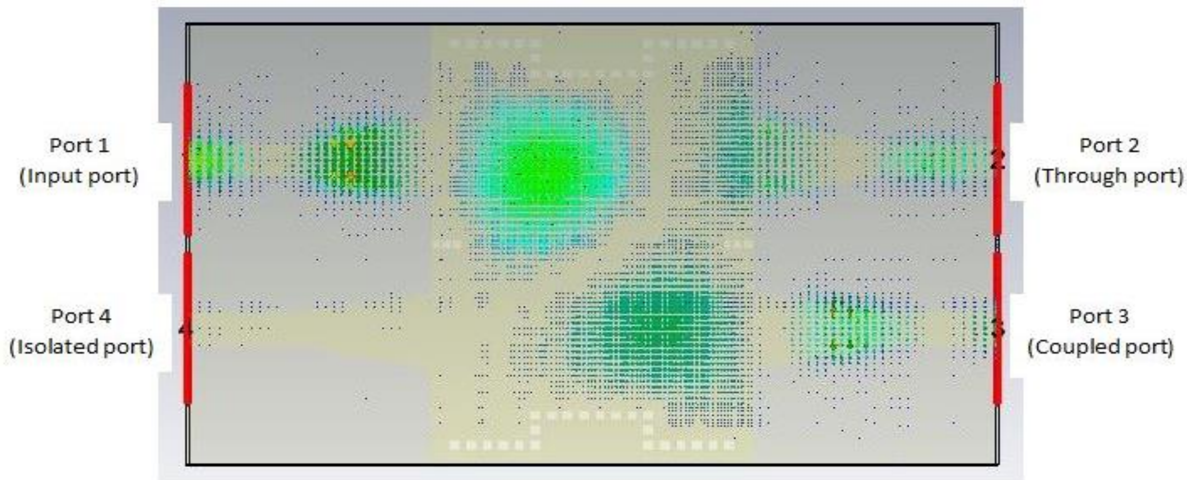

Figure 6. Electric field of SIW coupler

4.3 Simulated Phase of coupled between S_{21} and S_{31}

Figure 7 shows the graph of phase difference between port 2 and port 3 are calculated. As the simulation results, the phase difference is nearly 90 degree within frequency (19-25 GHz).

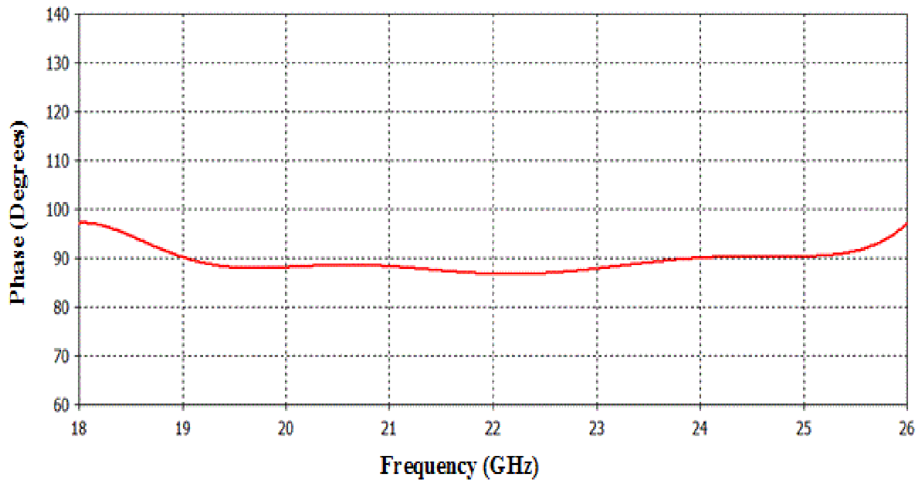

Figure 7. Phase Difference of SIW coupler

5. Conclusion

In this design, the Substrate Integrated Waveguide (SIW) coupler which based on the coupling theory for K-Band applications is analysed. The coupler is designed by using the Computer Simulation Software (CST) 2014 and material substrate Roger 4003C is used. The percentage bandwidth is more than 36.36%. S_{21} and S_{31} achieve the range of the requirement results which are -3 ± 1.5 dB meanwhile S_{11} and S_{41} obtain less than -10 dB. This designed coupler relatively has loss that can be improved by increasing the value of metal and substrate thickness. Coupling will be reduced as $W_{aperture}$ is decreased. Therefore, the simulation results show that the good performance of this designed coupler conceived in 18-26 GHz.

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