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Wideband Directional Coupler for X-band using SIW Technique

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***Abstract*: In this article, compact and wideband directional coupler has been proposed based on substrate integrated waveguide technique for X-band applications. The bandwidth of directional coupler has enlarged by tapering the coupling section. This coupler consists of two narrow apertures on the common broadside wall of two adjacent SIWs and four microstrips to waveguide transition line. Attractive features including compact size and planar form make this coupler structure easily integrated in antenna beam-forming networks. The coupling is about 7 dB at 9 GHz to 12 GHz frequency, the isolation is below 15dB over the frequency range of 9-12 GHz, and the return loss is better than 15dB. Design considerations and results are discussed and presented. A simulation has been carried out by Ansoft High frequency structure simulator (HFSS).**

Keywords: Substrate Integrated Waveguide (SIW), Coupling factor, Isolation, Return loss, Bandwidth.

I. INTRODUCTION

In RF and Microwave wave communication, directional coupler play vital role in RADAR (Radio Detection and Ranging) measurement systems, and antenna beam-forming networks [1]. Especially in the antenna beam-forming networks, power divider or combiner are required, and the directional coupler is generally an important element in power dividing/combing networks, so great interest and effort have been directed to the development of different types of directional couplers [2, 3].

Directional coupler is a four-port reciprocal, matched and lossless network, which can be structured in various forms, including waveguide directional couplers, hybrid junction, T-junction and branch line directional couplers in non-planar and planar form [4]. Rectangular waveguide directional couplers are broadly investigated [5]. It is well known that the rectangular waveguide structures have many advantages over planar transmission lines for millimeter band application, such as low loss, high Q, and high power handling capacity [6]. However, they are difficult to manufacture and integrate with planar circuitry due to their 3-Dimensional geometry.

This gap was filled by the proposed new planar substrate integrated waveguide (SIW) technique. The SIW structure is an integrated waveguide structure fabricated by using two rows of conducting cylinders embedded in a dielectric substrate that connect two parallel conducting plates. This dielectric filled waveguide structure has similar propagation modes as rectangular waveguide (non-planar) that is fabricated in planar substrate with periodic metallic cylinders. It fundamentally support TE_{10} mode. The SIW structure preserves most of the characteristics of microstrip structure and conventional metallic rectangular waveguide. For instance, propagation characteristics including the field pattern and dispersion characteristics are similar to classical rectangular waveguides [7]. For many microwave applications, a number of components based on the SIW technology have been proposed over the past years. Components such as filters [6], couplers [8], oscillators and slot array antenna. The fabrication of SIW is possible using standard Printed Circuit Board (PCB) technique [9]. Many researchers have shown that the SIW can be analyzed with waveguide theory, except that its width has to be replaced with the calculated equivalent width of SIW [10].

In this paper, we presented a simple configuration to realize the directional coupler, in which, the coupling is obtained by gap on the common broadside wall of two adjacent SIWs. In the paper, the design method is discussed, the parameter studies for SIW directional couplers are performed, and an X-band coupler is designed.

II. THEORY

This part consider two sections in which first section consider introductory of SIW for X-band and following to that next part is consider basic theory of direction coupler .

1. Design of SIW should be carefully to ensure that it support TE_{10} mode exclusively in the operating frequency range. The basic structure of SIW is shown in figure 1 in which top metal layer and ground layer within a substrate is connected by metallic vias. In this way, hollow metallic non planar waveguide can be created in the form of planar wave structure [4]. The propagation characteristics of a SIW structure such as field pattern and dispersion are similar to that non planar waveguide [3].

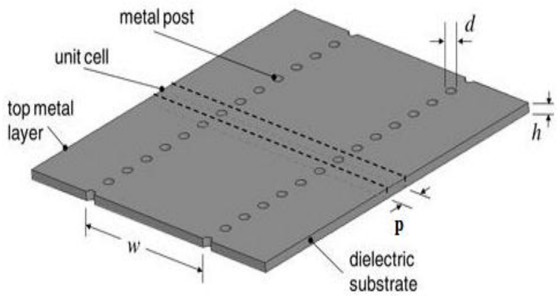


Figure 1: Basic Structure of SIW

As shown in figure 1, h is the height of the substrate, w is the width of the waveguide, p is the center to center distance between two metallic posts and d is the diameter of the metallic vias. As we aware that basically waveguide acts as a high pass filter and pass the energy depending upon the cut off frequency on which it has been designed. The cutoff frequency of the SIW is decided based on the height and width of the planar structure [13-15]. In SIW, the width between two posts can be calculated using equation

$$W = a_{equ} + \left(\frac{d^2}{0.95p}\right) \quad (1)$$

Where a_{equ} is the lateral centre to centre distance between two vias and can be calculated from the cutoff frequency equation [16, 17]

$$f_c = \frac{c}{2a_{equ}\sqrt{\varepsilon_r}} \quad (2)$$

Where f_c is the cutoff frequency, c is the velocity of light in free space ($3*10^8$ m/s), ε_r is the relative permittivity of the substrate material. Spacing between the posts (p) and the diameter (d) of post should be decided such that they should satisfied the condition shown in equation 3 otherwise it increases the dispersion loss [18, 19].

$$\left(\frac{d}{p}\right) < 2.5 \quad (3)$$

With the use of above equation, we have designed rectangular SIW for the specification given in table 1.

TABLE 1: DESIGN SPECIFICATION OF SIW FILTER

Parameter	Value
Cut-off frequency	8 GHz
Insertion Loss	Less than -2 dB
Return loss	More than -10 dB

With the use of above equations, we have designed X-band SIW for the cutoff frequency of 8 GHz (Consider the fundamental mode is TE_{10}). Figure 2 shows the electric field distribution within a SIW structure and the length of structure is chose in such a manner that the electric field generate maxima at both the ends [7]. For the feeding purpose and transition from microstrip line to the waveguide, tapered microstrip line is inserted and it is designed according to impedance matching characteristic. We have selected Arlon (AD300A) as the substrate material having a permittivity of 3, height (h) of the substrate is equal to 0.507mm, the diameter (d) of the post is 1.4mm, center to center distance (p) between the two posts is 2mm and width (w) of the waveguide is equal to the 11.83 mm. Simulated scattering parameters (S_{11} and S_{21}) of the structure is shown in figure.3 provides cut off frequency at 8 GHz and reflection coefficient has a value more than 15dB. Equivalent LC model and its scattering parameter of the structure that we have implemented in ADS simulator are shown in figure 4a and 4b.

TABLE 2: GEOMETRIC PARAMETERS FOR SIW FILTER

Parameters for corresponding rectangular waveguide for X-band	Value
Width of rectangular waveguide (mm)	11.83
Spacing between two posts (mm)	2
Diameter of tuning metallic via (mm)	1.4
Height of rectangular waveguide (mm)	0.507

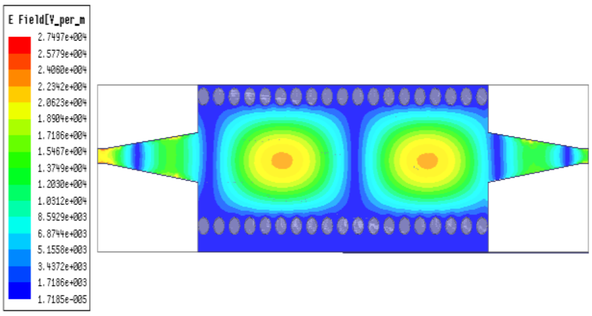


Figure 2: Electric field distributions in SIW Structure (Simulated in HFSS)

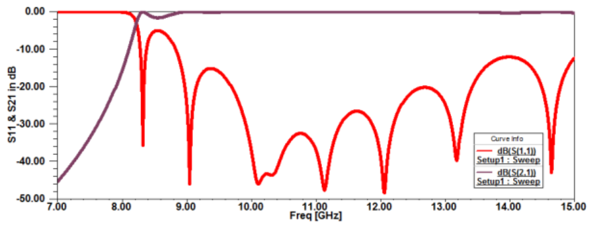
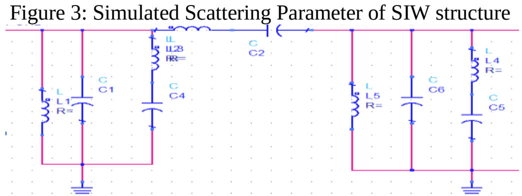
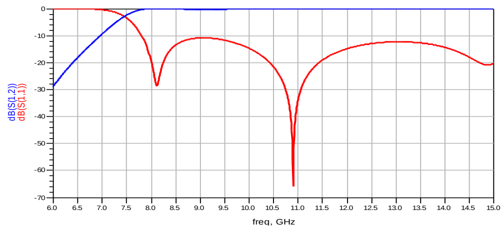


Figure 3: Simulated Scattering Parameter of SIW structure



(a)



(b)

Figure 4: (a) Equivalent LC model and (b) Scattering parameters of SIW structure for X-band

2. The basic configuration of four port forward directional coupler is as shown in figure 5 [2]. Here port 1 is the incident port (from where power is inserted). Port 2 is the through port (most of the power is incident on the port 1 is coupled to this port). Port 3 is a coupled port (some part of power incident on port 1 is coupled to this port). Port 4 is isolate port (ideally no power is coupled to this port, but practically some form of power is leaks to this port).

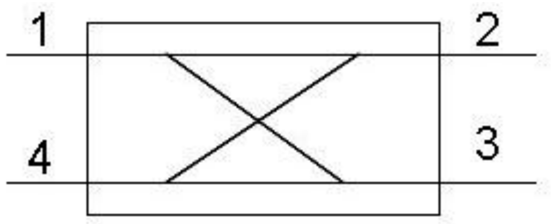


Figure 5: Basic structure of four port forward directional coupler

For signal incident at port 1 of power P_1 and output power P_2, P_3 and P_4 at port 2, 3 and port 4 respectively then

$$\text{Insertion loss (IL)} = 10 \log (P_1/P_2) = -20 \log (S_{21}) \quad (4)$$

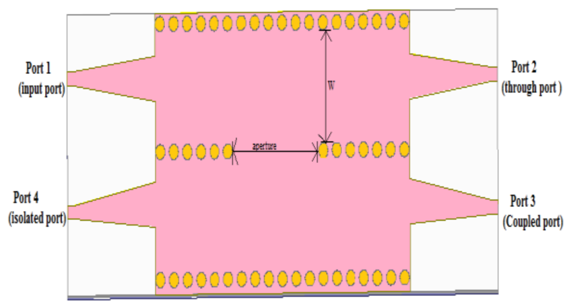
$$\text{Isolation (I)} = 10 \log (P_1/P_4) = -20 \log (S_{41}) \quad (5)$$

$$\text{Coupling (C)} = 10 \log (P_1/P_3) = -20 \log (S_{31}) \quad (6)$$

$$\text{Directivity (D)} = 10 \log (P_3/P_4) = -20 \log (S_{31}/S_{41}) \quad (7)$$

III. Design of Directional Coupler for X Band of Application

A proposed structure of the directional coupler based on SIW technique is shown in figure 6. Here port 1 is an input port, port 2 is a through port, port 3 is a coupled port and port 4 is isolated port. Here we have selected Arlon AD300A as a substrate material having a dielectric constant of 3 and dielectric loss tangent of 0.002, height of the structure is 0.508mm. The major design consideration for direction coupler is the width (of main arm and collinear arm) and aperture gap (between main arm and collinear arm). Here, we have selected width of the structure (W) is 6.33mm and aperture gap is equal to the 12.6mm.



(a)

Figure 6: 2D model of the proposed direction coupler

IV. Simulation Results

The proposed structure of SIW based direction coupler has been simulated by using High frequency Structure Simulator [18]. The flow of electric field in all the four ports is shown in figure 7. A simulated Scattering parameter of the structure is shown in figure 8.The simulated results shows that most of the power incident at port 1 is coupled to the port 2. It provides the insertion loss of around -1.5 dB from the frequency range of 9 GHz to the 12 GHz that shows it provides bandwidth of 3GHz. Some of the power incident at the port 1 is coupled to the port 3. It provides the insertion loss around -6.22 dB for same frequency range. Moreover, it gives better isolation (more than -16 dB) at port 1 (input port) and at port 4 (isolation port) more than -16dB. The Simulation result of all the reflection coefficients of all the ports is shown in figure 9.

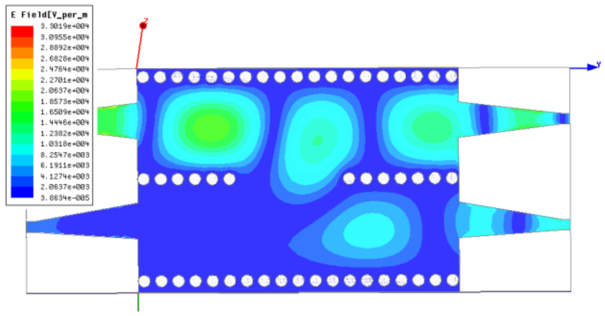


Figure 7: Electric Field Distribution in the proposed structure

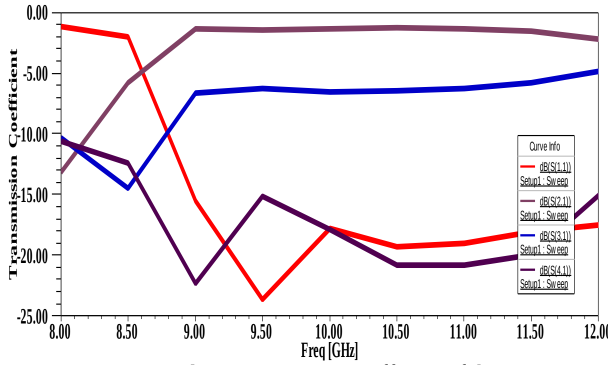


Figure 8: Simulate Transmission Coefficient of the Structure

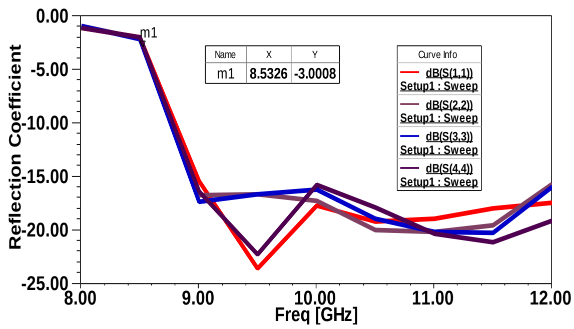


Figure 9: Simulate Reflection Coefficient of the Structure

The Phase difference between port 2 (through port) and port 3 (coupled port) result is shown in figure 10. It indicates the phase difference between these ports is around 90 degree which is used for antenna beam forming. Figure 5 shows the electrical field distribution in the structure. From the Figure, it indicates that the most of the power incident at port 1 is coupled at port 2 and at the port 3; Port 4 is the isolate port however in consequential power is coupled to this port.

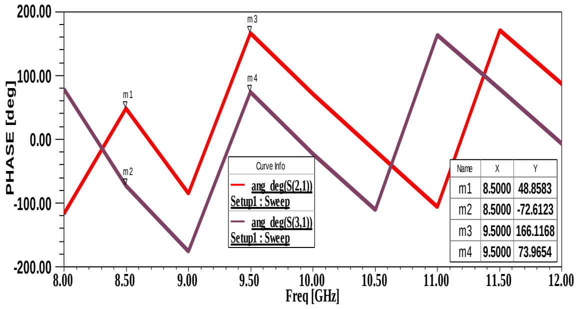


Figure **10**: Simulate phase difference at port 2 and port 3 when input is at port 1

V. Comparison

We have compared the proposed SIW based directional coupler with traditional X-band directional coupler in terms of insertion loss, coupled power, isolation and bandwidth which is tabulated in table 3.

Table 3: Comparison of proposed structure with traditional structure [20]

Structure	Insertion loss in dB	Coupling in dB	Isolation in dB	Bandwidth in GHz
Traditional [20]	-3.78	-3.82	-13	2
Proposed	-1.5	-6	-18	3

VI. Conclusion

It is observed and concluded from the simulated results that the proposed directional coupler show better performance with 3 GHz wideband bandwidth, low insertion loss, low return loss and high isolation. The characteristics of compact size and planar form make such SIW directional couplers to easily integrate in microwave and millimeter-wave planar circuits. The fabrication process of the proposed structure can simply be done by using standard Printed Circuit Board (PCB) process so that the cost of the fabricating process will be minimized with respect to the conventional waveguide.

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