Design of microwave planar directional coupler based on Substrate Integrated Waveguide

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***Abstract*—Planar directional coupler using Substrate Integrated Waveguide technology (SIW) is proposed in this paper. The SIW coupler with tapered microstrip-SIW transitions are integrated on the same substrate.**

Planar form makes this coupler structure easily integrable in microwave planar circuits. These proposed power dividers can be applied to the design of the beam-forming network for communication system.

This structure is designed with Finite Element Method (FEM) using HFSS on a single substrate of ARLON 1000. Simulated results are presented and discussed.

***Index Terms*— Substrate integrated waveguide (SIW), directional coupler, transition, via-holes, microstrip technology.**

I. INTRODUCTION

Directional couplers are widely used in many microwave and millimeter systems, such as in precision measurement systems, six port transceiver, mixer, beam-forming and other antenna feeding networks.

The low power dissipation of the rectangular waveguide allows the designs of high Q components. However, the manufacturing of rectangular waveguide structures is rather expensive. Furthermore, the integration of such structures with planar circuits requires specific sophisticated transitions. Microstrip lines are, in comparison, easy and not expensive to fabricate, but are not low loss radiation and not shielded.

The SIW is an intermediate structure. This technology has been successfully used to design of microwave and millimeter-wave couplers which are widely exploited extensively as a key block in modern communication systems [1]-[2]-[3].

The SIW is an excellent candidate for the integration of high density millimeter wave circuits which require a good quality factor. It benefits from the very low production cost of the PCB process and is relatively compact. They are constructed by metal filled via-hole arrays in substrate and grounded planes which can be easily interconnected with other elements of the system on a single substrate plat form without tuning [4]-[5]-[6]., this system can be miniaturised into small package called the system in pakage SIP which has small size and low cost [7]. A schematic view of an integrated waveguide is shown in Fig. 1.

In this paper, the Finite Element Method (FEM) based on a commercial software package "HFSS" has been applied to the analysis of the SIW structures. Firstly we give design equations for tapered microstrip-SIW transitions, and then we focus on the design of SIW coupler with these transitions around 5 GHz. No isolation resistors are required to achieve the high isolation performances in this kind of design.

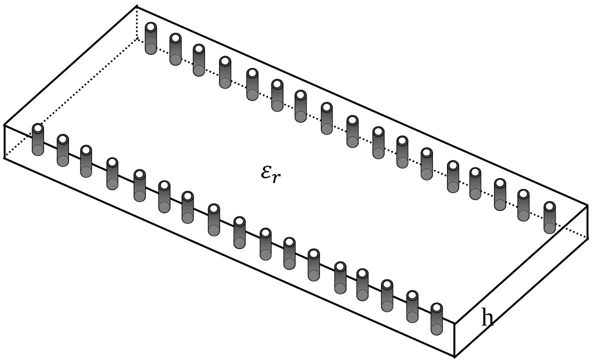

Fig. 1: Topology of the substrate Integrated Waveguide

II. CONFIGURATION AND DESIGN TECHNIQUE OF TRANSITION

In order to combine SIW and microstrip technologies, microstrip-SIW transitions are very required [8]-[9]. Tapered transition shows in Fig.2 have been studied.

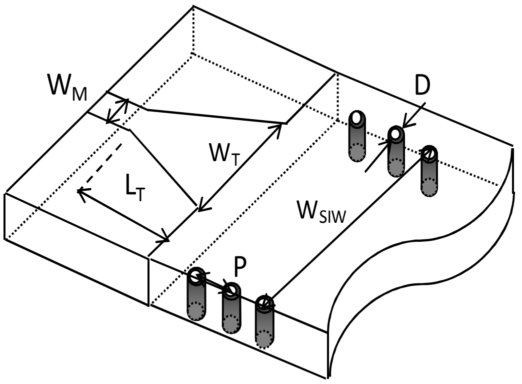

Fig. 2: Configuration of the microstrip to SIW transition

This transition consists of the tapered microstrip line and the step between the microstrip and the rectangular waveguide. The geometry of a microstrip line is shown in Figure 3.

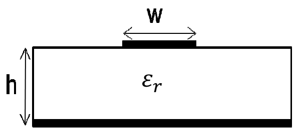

Fig. 3: Geometry of microstrip line

When $\frac{W}{h} \geq 1$, the effective dielectric constant of a microstrip line is given approximately by [10]:

$$\varepsilon_e = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{12h}{w}\right)^{-\frac{1}{2}} \tag{1}$$

The effective dielectric constant can be interpreted as the dielectric constant of a homogeneous medium that replaces the air and dielectric regions of the microstrip, as shown in Fig. 4.

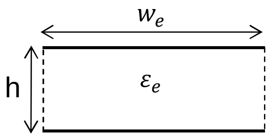

Fig. 4: Equivalent geometry of microstrip line

The impedance of the waveguide model (Fig.4) is given by:

$$Z_e = \sqrt{\frac{\mu}{\varepsilon_0 \varepsilon_e}}\frac{h}{w_e} \tag{2}$$

Combining with the equation for the impedance of microstrip line, we obtain:

$$Z_e = \begin{cases} \frac{60}{\sqrt{\varepsilon_e}}\ln\left(8\frac{h}{w}+\frac{w}{4h}\right) & w/h \leq 1 \\ \frac{120\pi}{\sqrt{\varepsilon_e}}\left[w/h + 1.393 + 0.667\ln\left(w/h + 1.444\right)\right]^{-1} & w/h > 1 \end{cases} \tag{3}$$

The taper is used to transform the quasi-TEM mode of the microstrip line into the TE_{10} mode in the waveguide. It is known that the propagation constant of the TE_{10} mode is only related to the width "W_{SIW}". Therefore, the scattering parameters are independent of the height or thickness "h" of the waveguide. The scattering parameters are then only dependant of: w_{SIW}, w_e, ε_e and ε_r.

These parameters, in the normalized frequency band, are related to the ratios: $\frac{w_{SIW}}{w_e}$ and $\frac{\varepsilon_e}{\varepsilon_r}$.

Curve fitting techniques have been used by Deslandes in [11] to find the relation between permittivity and width ratios. This relation is given by:

$$\frac{w_{SIW}}{w_e} = 4.38e^{-0.627\frac{\varepsilon_r}{\varepsilon_e}} \tag{4}$$

Combining equations (1) and (4), we obtain:

$$\frac{1}{w_e} = \frac{4.38}{w_{SIW}}e^{-0.627\frac{\varepsilon_r}{\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left(1+\frac{12h}{w}\right)^{-\frac{1}{2}}}} \tag{5}$$

Combining equations (2) and (3), we obtain:

$$\frac{1}{w_e} = \begin{cases} \sqrt{\frac{\varepsilon_0}{\mu}}\frac{60}{h}\ln\left(8\frac{h}{w}+0.25\frac{w}{h}\right) & w/h \leq 1 \\ \sqrt{\frac{\varepsilon_0}{\mu}}\frac{120\pi}{h\left[\frac{w}{h}+1.393+0.667\ln\left(\frac{w}{h}+1.444\right)\right]} & w/h > 1 \end{cases} \tag{6}$$

We can equate the equations (5) and (6) and solve it to obtain w, which is the optimum taper with.

Since the E field distribution in the SIW looks like that of a classic rectangular waveguide, the width w_{SIW} can be approximated as follows [12]:

$$w_{SIW} = w - \frac{D}{0.95P} \tag{7}$$

In this equation, w is the width of the dielectric waveguide. The parameters D and P are the wall post diameter and the period of vias respectively as shown in Fig.2.

The taper length L_T must be chosen as a multiple of a quarter of a wavelength in order to minimise the return loss.

III. DESIGN OF DIRCTIONAL COUPLER

The geometry of the SIW directional coupler is schematically illustrated in Fig. 5.

In this structure, four ports are named as input port (port 1), through port (port 2), isolation port (port 3), and coupling port (port 4) respectively. This kind of coupler consists of two waveguides coupled by slot. The coupling ratio at port 4 can be controlled by changing the size of the coupling slot.

The advantages of this work include compact design, good compatibility with planar circuits, and no need to use isolation resistors.

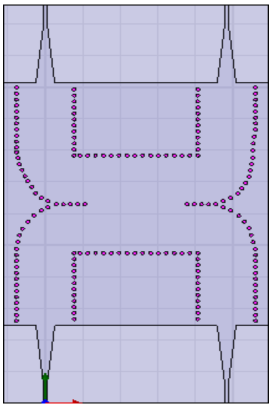

Fig. 5: Configuration of SIW directional coupler

The SIW directional coupler is constructed into one substrate with height $h=1.27$ mm, dielectric constant $\varepsilon_r = 10.2$ and $tg\delta = 0.0023$, $w_{SIW} = 15.44\,mm$ is the width of SIW. The post diameter is D =1 mm and the P=1.9 mm is the cylinder spacing, while L=27 mm is the length of the coupling slot.

The design of transitions coupler is very critical and important in order to have good performance. Solving graphically equations (5) and (6) for the optimum microstrip width, we can find $w = w_T = 5\ mm$. The taper length is equal to L_T= 17.5 mm, which represented three quarters of a wavelength.

The coupler proposed is done with HFSS using the Finite Element Method (FEM). Fig. 6 shows the cross-sectional view of the electric field distribution in SIW coupler with tapered transitions.

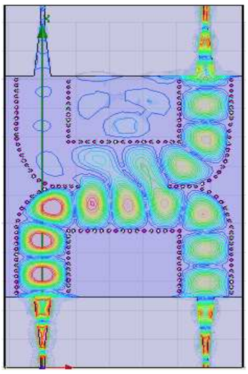

Fig.6: Electric fields distributions in SIW directional coupler

Figure 7 illustrates the simulated performance of the 3 dB directional coupler. The return loss less than 20 dB and the isolation is also than 20 dB around 5.1 dB, the difference between the simulated insertion loss at ports 1 and 4 less than 0.5 dB.

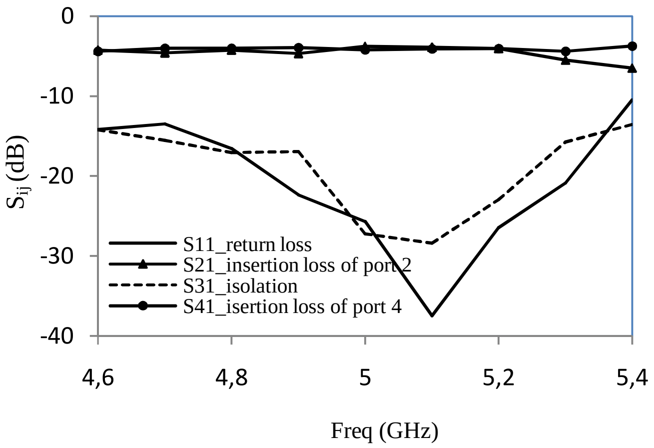

Fig. 7: Simulation S parameters of SIW coupler

Fig.8 shows the simulated relative phase difference between two output ports 2 and 4 of the coupler. The phase difference between S_{21} and S_{41} is nearly 90°.

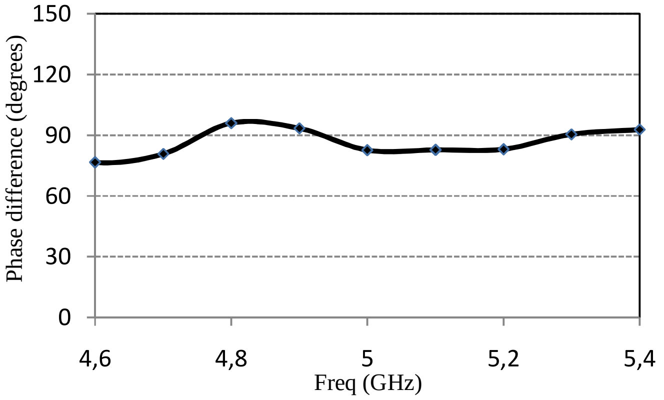

Fig. 8: Simulation results for the phase difference between two output ports

IV. CONCLUSION

SIW directional coupler with SIW-microstrip transitions have been presented in this paper.

The coupler shows good performance in terms of return and insertion losses. The main characteristics of these kinds of SIW structures are low size, high power handling and easy to manufacture. Our results show that we do not need the manual tuning or adjustment after fabrication.

Future work should be done for further increasing the bandwidth of SIW couplers.

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