# Compact Size, Equal-Length and Unequal-Width Substrate Integrated Waveguide Phase Shifter

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***Abstract* — In this letter a novel substrate integrated waveguide (SIW) phase shifter is proposed. It consist of phase channels made by SIW with equal length and unequal width. Design equations and process are given with mathematical analysis. The propagation constant of the output signals have been adjusted by changing only the width of the output arms. As a result a novel phase shifter, is obtained accordingly. The experimental results of a prototype at 10 GHz shows 45 degrees phase difference between two outputs. Return loss and transmission coefficient are good agreement with simulation results in considered band.**

***Keywords*— Phase shifter, SIW, compact size**

## I. Introduction

The phase shifter is an essential component for realization of many microwave circuits. It is mainly used to phase shift in array antennas and many other communication systems [1]-[3] such as wireless communication systems, radar systems, industrial and biomedical imaging systems. This type of circuit is mainly designed in the micro strip form [4]-[6]. Wave guide power dividers and phase shifters have lower loss or dissipation in comparison to micro strip lines especially in higher frequencies of operation.

Substrate integrated waveguide is a new structure which has become salient in recent decades because of its low weight, small size and easily integrate with other microwave component. There are different approach to make a phase shifting in a substrate integrated waveguide [7]-[9]. In this paper the width of the output channels have been changed. The most significant advantage of this design is using one input as the feed on the contrary to other existing designs that apply several inputs as the feed [7]-[8]. MEMS phase shifters require a DC bias while in the proposed phase shifter designed, here there is no bias at all.

Figure 1 represents the proposed phase shifter with equal output powers which consists of three ports. Port 1 is the feed of the structure, and port 2, 3 are the out puts of the phase shifter.

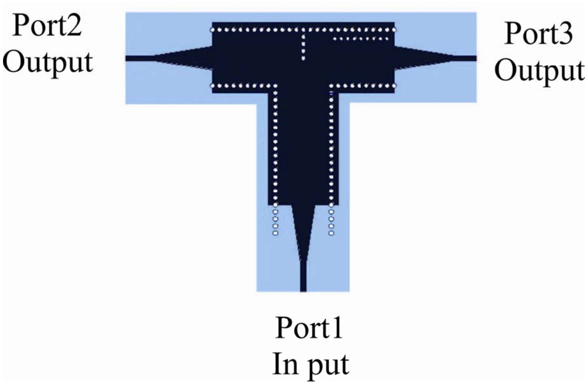



**Figure 1.** Structure of phase shifter.

## II. ANALYSIS AND DESIGN

SIW is a quasi-rectangular waveguide formed by the periodic via-hole connections between two metal layers. In the TE mode (dominant mode), SIW is equivalent to a conventional rectangular waveguide with negligible leakagelosses. Therefore SIW and its equivalent dielectric field waveguide share the same $TE_{10}$ mode cut-off frequency as follows:

$$f_c = \frac{1}{2a\sqrt{\mu\varepsilon}} \quad (1)$$

where a is the width of the rectangular waveguide equivalent of SIW, μ and ε are the permittivity and permeability of the substrate, respectively.

The width of the rectangular waveguide equivalent and fundamental properties of SIW are given approximately in [10] as follows:

$$a = A - \frac{D^2}{0.95P} \quad (2)$$

where a is the width of the equivalent rectangular waveguide, A is the width of SIW, D is the diameter of metalized via holes and P is the pitch between adjacent via holeas shown in Figure 2 The proposed phase shifter and its dimensions are shown in Figure 3 and Table 1 respectively. Generally in a transmission line electrical length of the line is depend on the propagation constant (β) and the physical length (l)

$$\theta = \beta l \quad (3)$$

In order to achieve phase shifting β or l can be changed. The size of the structure will be large if the length (l) has been changed. Therefore β has been preferred to make phase shifting. By considering the waveguide equivalent for SIW the guided wavelength and propagation constant are given as following:

$$\lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{\lambda}{2a}\right)^2}} \qquad \beta = \frac{2\pi}{\lambda_g} \quad (4)$$

Where a is the width of the rectangular waveguide equivalent of SIW. Accordingly, the guided wavelength and propagation constant of the SIW could be controlled by the width of the SIW.

Therefore the design procedure is start by considering the desired phase shift (θ). Then for a given physical length (l), propagation constant (β) and guided wavelength ($\lambda_g$) will be found. Finally the width of the SIW (a) will be calculated. The above technique is used in the proposed SIW phase shifter by adding extra row of vias in the one of the output arms as shown in Figure 3. So the output arms have different widths and same length. Therefore the propagation constant and the phase of the output signals will be different.

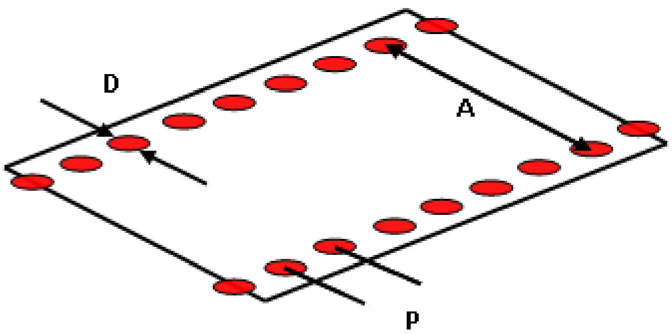



**Figure 2.** Rectangular wave guide integrated into a substrate.

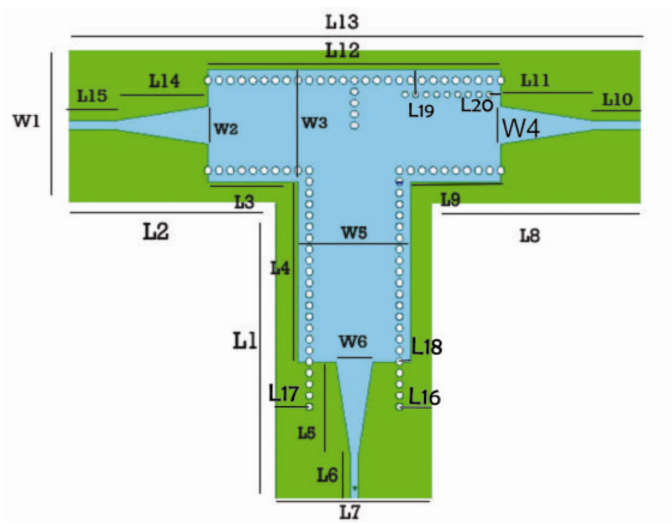



**Figure 3.** Geometry of the phase shifter.

**TABLE 1.** DIMENSIONS OF CONVENTIONAL PHASE SHIFTER

| parametr | mm | parametr | mm |
|---|---|---|---|
| L6 | 6.5 | L2 | 28 |
| L5 | 12.5 | L13 | 77 |
| W1 | 21 | L12 | 39 |
| W3 | 15 | L4 | 24 |
| W2 | 5 | L1 | 40 |
| L3 | 12 | L18 | 1.5 |
| L16 | 4.5 | L19 | 3.37 |
| L17 | 4.5 | L20 | 1.55 |
| L9 | 12 | W4 | 5 |
| W6 | 5 | W5 | 15 |
| L7 | 21 | L8 | 28 |
| L10 | 6.5 | L15 | 6.5 |
| L11 | 12.5 | L14 | 12.5 |

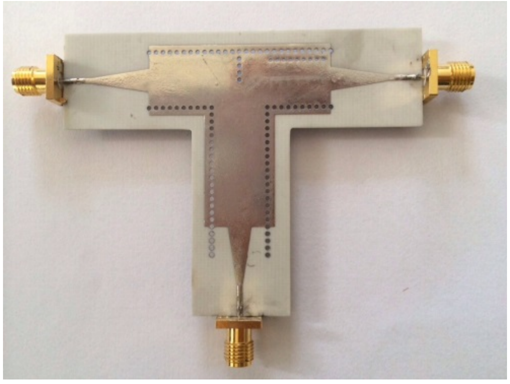
After some optimization in smulation with HFSS software, thr appropriate parameters of the structure can be obtained to make desire phase shifting. With changing the parameter of $L_{19}$, different values of phase shifting are acquired. For the prototype the phase shift of 45° has been applied.

One of the output channel width has been reduced with using 9 holes.The values of (P) and (D) for these 9 holes are 1.4 mm and 0.8 mm respectively. Also there are 4 holes in the middle of the structure to divided the input signal equally between two outputs for which the values of (P) and (D) are 1.5 mm and 1mm respectively. The designed phase shifter was etched onto a piece of Rogers 4003with $\varepsilon_r$=3.55, tanδ =0.0027 and thickness of substrate layer is 0.508.

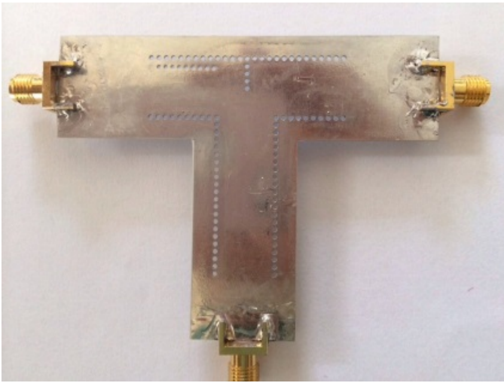
## III. MEASUREMENT RESULTS

The fabricated SIW phase shifter at the frequency of 10 GHz is shown in Figure 4. Top and bottom views of the fabricated component are shown in Figure 4 (a) and 4 (b) respectively. Figure 5 (a), (b) show the simulated and measured values of the S-parameters in SIW phase shifter respectively. As can be seen from the measurement results, 2 GHz bandwidth can be obtained. The differences between the results of measurement and simulation are due to the effects of the SMA connectors soldered into structure and the fabrication process.

Figure 6 shows the simulation and measurement results for phase responses. Figure 6 (a) represents the measurement phases of the output signals, the comparison between simulation and measurement results and output phase difference are illustrated in Figure 6 (b), (c) respectively. There is good agreement between simulation and measurement results.

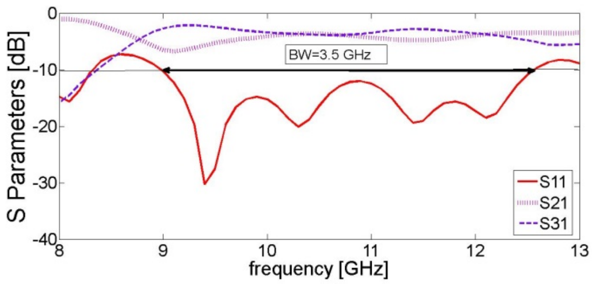


(a)

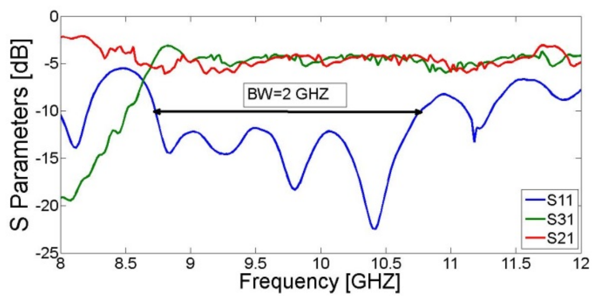


(b)

**Figure 4.** phase shifter (a) top (b) bottom view.

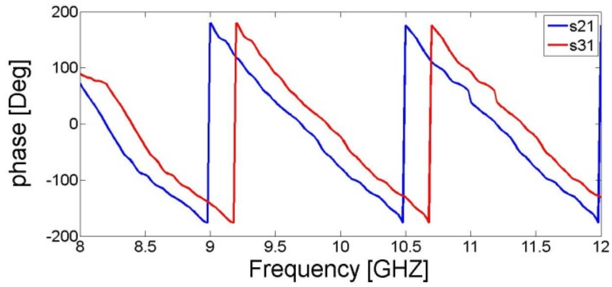



(a)

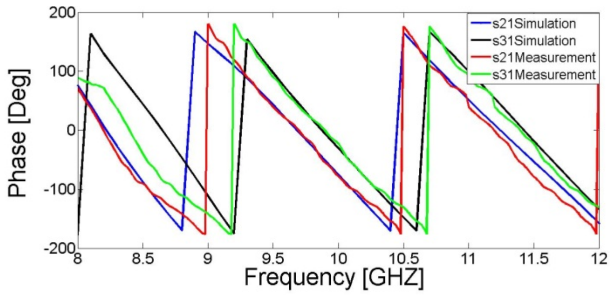



(b)

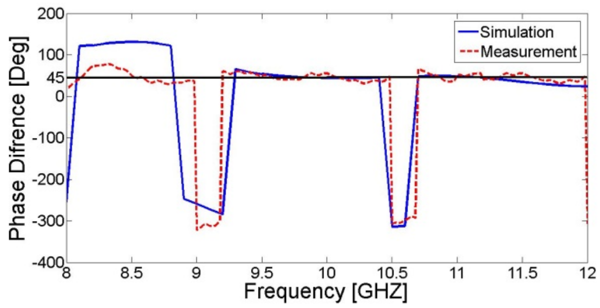
**Figure 5.** The S-parameters of SIW phase shifter (a) simulation (b) measurement.




(a)




(b)




(c)

**Figure 6.** Phase responses (a) Measured of outputs (b) simulation and measurement (c) phase difference between outputs.

## IV. CONCLUSIONS

A novel phase shifter based on SIW technology with the equal length and unequal width output channels is proposed. The proposed SIW phase shifter has one input and two equal length outputs, therefore it has compact size in comparison with available SIW phase shifters. Detailed of the design procedure is completely explained. The correctness of the analytical approach is validated by measurement results of a SIW 45$^{o}$ phase shifter. Therefore such a SIW phase shifter is a good candidate for development of a compact size and integrated microwave systems.

## REFERENCES


[1] D. M. Krafcsik, S. A. Imhoff, D. E. Dawson, and A. L. Conti, "A dual-varactor analog phase shifter operating at 6 to 18 GHz," *Microw. Theory Tech. IEEE Trans.*, vol. 36, no. 12, pp. 1938–1941, Dec. 1988.

[2] K. Sellal, L. Talbi, T. A. Denidni, and J. LeBel, "Design and implementation of a substrate integrated waveguide phase shifter,"

*Microwaves, Antennas Propagation, IET*, vol. 2, no. 2, pp. 194–199, Mar. 2008.
[3] E. Sbarra, L. Marcaccioli, R. V Gatti, and R. Sorrentino, "Ku-band analogue phase shifter in SIW technology," in *Microwave Conference, 2009. EuMC 2009. European*, 2009, pp. 264–267.
[4] B. Schiek and J. Kohler, "A Method for Broad-Band Matching of Microstrip Differential Phase Shifters," *Microw. Theory Tech. IEEE Trans.*, vol. 25, no. 8, pp. 666–671, Aug. 1977.
[5] J. L. R. Quirarte and J. P. Starski, "Novel Schiffman phase shifters," *Microw. Theory Tech. IEEE Trans.*, vol. 41, no. 1, pp. 9–14, Jan. 1993.
[6] S.-Y. Eom, "Broadband 180 deg; bit phase shifter using a lambda;/2 coupled line and parallel lambda;/8 stubs," *Microw. Wirel. Components Lett. IEEE*, vol. 14, no. 5, pp. 228–230, May 2004.
[7] Z.-Y. Zhang, K. Wu, and Y. R. Wei, "Broadband delay compensation phase shifter using slotted substrate integrated waveguide structure," in *Microwave Symposium Digest (MTT), 2011 IEEE MTT-S International*, 2011, pp. 1–4.
[8] Y. J. Cheng, K. Wu, and W. Hong, "Substrate integrated waveguide (SIW) broadband compensating phase shifter," in *Microwave Symposium Digest, 2009. MTT '09. IEEE MTT-S International*, 2009, pp. 845–848.
[9] T. Yang, M. Ettorre, and R. Sauleau, "Novel Phase Shifter Design Based on Substrate-Integrated-Waveguide Technology," *Microw. Wirel. Components Lett. IEEE*, vol. 22, no. 10, pp. 518–520, Oct. 2012.
[10] X.-P. Chen and K. Wu, "Substrate Integrated Waveguide Filter: Basic Design Rules and Fundamental Structure Features," Microwave Magazine,IEEE, vol. 15, pp. 108–116, July 2014.

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