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28 GHz Digital SIW Phase Shifter Using Embedded PIN Diodes

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***Abstract*— This paper presents a new approach for designing of a controllable phase shifter based on integrated substrate waveguide (SIW) technology and PIN diodes for 5G millimeter wave wireless communication applications. The proposed phase shifter operates at 28 GHz with a wide bandwidth (14%) from 26 GHz to 30 GHz. The proposed geometry is designed and optimized by numerical simulation (HFSS) and results show a good agreement and a maximum differential phase of 99.99° at the central frequency (28GHz). The phase difference is provided by metal poles which are switched by PIN diodes and achieved a good performance regarding return loss and insertion loss.**

Keywords: Beam steering, Phase shifter, SIW, PIN diode, mm-wave

I. INTRODUCTION

Low and high Q-factor conventional waveguides with broad bandwidth are suitable for the designing of microwave millimeter-wave structures [1]. However, due to their large sizes, relatively high cost, and difficulty of integration, it becomes challenging to use them in low-cost high-volume applications. In [2], the authors proposed the concept of Substrate Integrated Waveguide. This concept is based on the building of via holes arrays synthesized and metalized posts embedded in the same substrate. The connection between the waveguide and the planar circuit is provided via transitions consisting of simple matching geometry between both structures and straightforward integration with other circuits. In this work, we propose a reconfigurable phase shifter based on a switching PIN diode interconnecting an annular ring gap within the metal post and the top metal wall of the SIW line.

II. PHASE SHIFTER DESIGN

In [3], the authors implemented a new approach of designing a high-pass filter based on a vertical metal post inserted into a rectangular waveguide. They derived the following phase equation in terms of waveguide parameters:

$$\phi = \tan^{-1}\left[\frac{B_n + 2X_n - B_n X_n^2}{2(1 - B_n X_n)}\right] \tag{1}$$

where X_n is the reactance and B_n is the susceptance of the high pass filter. These two parameters depend on the diameter d and the position P of the metallic vias. The phase is varying in terms of the diameter and the position of the metallic vias in the rectangular waveguide [2].

Among all the different approach of realizing a phase shifter circuit SIW technology, the insertion of vertical metal posts in the SIW waveguide is the best. This approach is equivalent to a T-high pass filter. Such technique introduced a fixed quantity of phase shift in a SIW circuit. In this work we used this technology due to advantage that it provides in the design of cheaper, reliable and robust millimeter wave RF components. This work proposes a novel controllable SIW phase shifter, using 4 metal posts that can be switched such that it provides either an inductive or a capacitive loading of the SIW transmission line. The ROGERS RT/Duroid 5880 substrate with a relative permittivity of ε_r = 2.2 is considered during the parametric study and the results are presented in Table I. The obtained design is illustrated below in Fig.1.

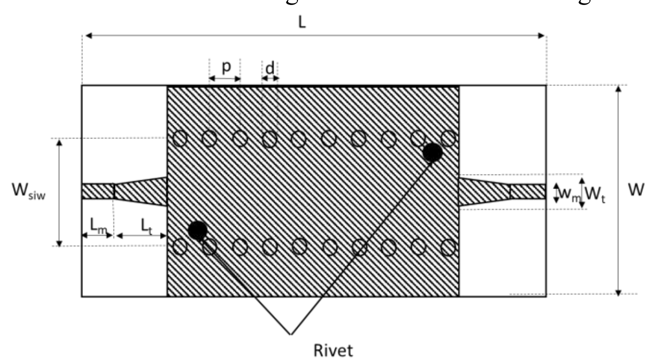

Figure 1. The SIW phase shifter with two rivet

Table I. PARAMETER VALUES OF THE PHASE SHIFTER

L	W	L_m	W_m	L_t	W_t	p	d	W_{SIW}
24.756	*107*	*1.95*	*0.76*	*3*	*0.38*	*1.5*	*0.9*	*5.57*

To realize the new phase shifter, we have inserted two inductive posts into the SIW structure. Later, we performed simulations using the HFSS EM simulator. Firstly, we proceeded by simulating the structure without metal posts. Secondly, we repeated the process by adding two posts diagonally symmetrical as shown in Fig.1. After having performed simulations, we listed the results in Table II.

As an observation, we pointed out the improvement of the phase shifting when using the posts. In Fig. 2, the reflection coefficient graphs illustrate the best matching of the device when using the posts compared to conventional one. Moreover, the posts have improved the phase shifting.

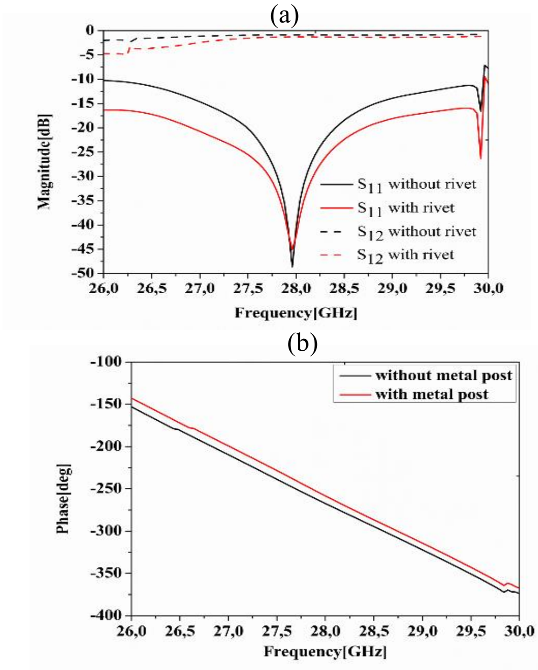

Figure 2. Simulated result in terms of (a) Magnitude and (b) Phase.

Table II. SIMULATION RESULTS OF THE PHASE SHIFTER AT 28 GHZ

Combination	Return Loss	Insertion Loss	Phase
Without rivet	***38.4 dB***	***1.5 dB***	***89.9°***
With rivet	***39.49 dB***	***1.32 dB***	***99.99°***

The next step of our work is to study the impact of metal posts in the design in which a ring gap is created between the posts and the top of the SIW line. We embedded the PIN diodes in those holes to ensure the achievement of the required phase shift as illustrated in Fig 3. The diode has been modelled with a low value resistor in series with an inductance when it is in the ON state (with RON= 6.5Ω), and with a high value resistor in parallel with a capacitor when it is in the OFF state (with ROFF= 10KΩ and COFF=0.02pF).

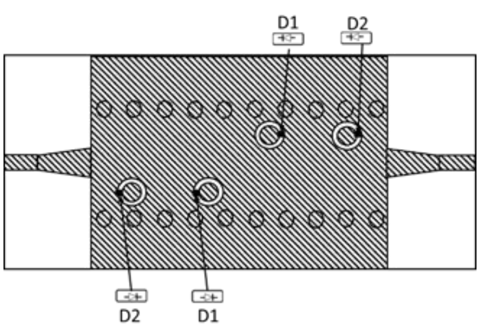

Figure 3. The SIW phase shifter proposed

Fig 4. Shows a good insertion and return loss in the frequency range from 26 to 30 GHz. The overall value of those parameters attest that the device is well matched since the minimal value of S11 is less than 15 dB. Regarding the return loss S21, the value is less than 2 dB which corresponds to a loss of less than the half of the transmitting power. Table 3 summarizes these results.

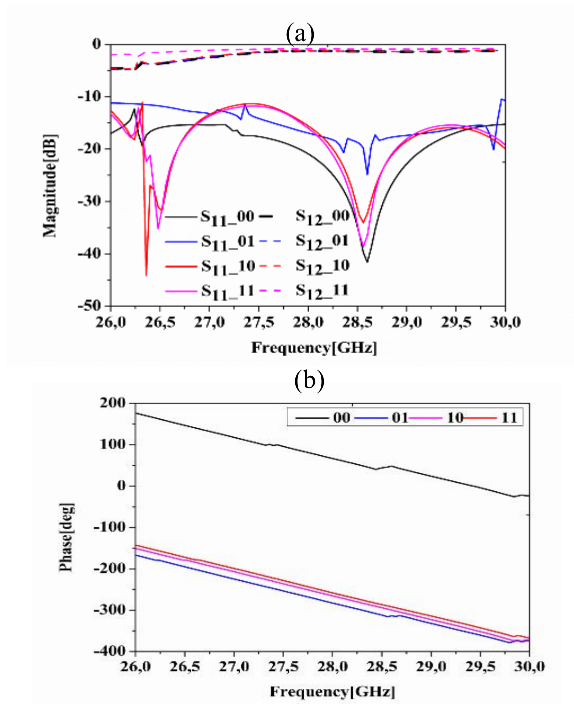

Figure 4. Simulated result in terms of (a) Magnitude and (b) Phase

Table III. SIMULATION RESULTS OF THE PHASE SHIFTER AT 28 GHZ

combination	Return Loss	Insertion Loss	Phase
00	***21.08 dB***	***1.25 dB***	***45.41°***
01	***16.20 dB***	***1.27 dB***	***77.81°***
10	***17.46 dB***	***1.25dB***	***75.9°***
11	***17.42 dB***	***1.32dB***	***100.99°***

III. CONCLUSION

In this paper a novel approach to the design of a broadband SIW phase shifter using reconfigurable metal posts has been presented. To demonstrate the proposed concept, a phase shifter operating over the main 5G candidate frequency bands (26 GHz – 30 GHz) has been designed and optimized using ANSYS HFSS. The proposed SIW phase shifter is easy to fabricate and can be integrated with other planar circuits for beamforming in 5G antenna arrays.

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