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A Novel Compact Planar Phase Shifter with a Microstrip Radial Stub

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Abstract: This paper presents a novel compact phase shifter with simple planar structure. The configuration consists of a microstrip line and a microstrip radial stub to implement wide-band phase shifting functions. Changing the length of the microstrip line and the angle of the radial stub, arbitrary phase differences can be obtained. For demonstration purpose, a 45° and 90° phase shifter are designed, fabricated and measured. The good agreements verify our proposed structure and design method. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Compact, Planar, Phase shifter, Microstrip, Radial stub.

1. Introduction

Phase shifters are widely used in many microwave circuits. They are most important components in phase-array antenna systems in which they are used to control phases. With the development of wireless communications, more and more compact and simple phase shifters are needed. Phase shifters can be made of coupled lines [1] and microstrip lines [2] for simple structures. To get larger bandwidth for coupled-line structure, tighter couplers are needed which increases the difficulty of fabrication [3]. To avoid using too closed coupled lines, [4] proposed a structure of two layers of microstrip substrate to get tight coupling performance through locating an elliptical slot in the mid layer. But the multilayer substrate leads to high complexity and cost. Compared to [1, 5-7] presented the modified Schiffman phase shifters with a patterned ground structure, which has the drawback of bringing serious radiation in this structure. Transmission-line phase shifters have planar structures. They always use open or shorted stubs loaded onto a long transmission line to realize phase shifters [8, 9]. But these structures often need a large ground and high impedance stubs which lead to a big size circuit board. Other methods have been presented to realize phase shifters [10-13]. But using reactive components in [10-12] and a vertically installed coupling structure in [13] are not suitable for mass production.

In this paper, a novel compact planar phase shifter is presented. The structure of the phase shifter is very simple which is composed of a microstrip line and a microstrip radial stub. As an alternative to the conventional straight stub, the radial stub has the advantages of a very low characteristic impedance and an accurate localization of the impedance reference plane [14, 15]. The phase shifter can realize any phase shift degrees flexibly with the transmission line of different electrical length. Through adjusting the radius and the sector angle of the radial stub, phase shifters with good performance can be achieved. The available design parameters of typical examples are presented. Two phase shifters of 90° and 45° phase degree are designed, fabricated, and measured. The calculated and measured results verify our proposed idea.

2. The Proposed Circuit and Design Approach

The circuit configuration of the proposed phase shifter is shown in Fig. 1. The structure consists of a microstrip line which characteristic impedance is 50 Ω and a shunt microstrip radial stub which characteristic impedance is defined by its geometry parameters. The geometries and the parameters of the shunt radial stub are shown in Fig. 2. Parameters φ (sector angle of the radial stub) and r_o are to be determined. The input impedance of the radial stub is [16]

$$Z_{in} = -j\frac{60\pi h}{\varphi\sqrt{\varepsilon_e}}\frac{[\ln(\beta r_i/2)+\gamma]\beta^2 r_o^2+4}{(r_o^2-r_i^2)\beta} - jh\frac{2}{\varphi}\frac{1}{(r_o^2-r_i^2)}\left(\frac{\omega\mu}{\beta^2(1-\varepsilon_e)}+\frac{1}{\omega\varepsilon_e}\right), \quad (1)$$

where $\beta = 2\pi\sqrt{\varepsilon_e}/\lambda_0$, ε_e is the equivalent relative permittivity of the microstrip with the width of $w=(r_i+r_o)\sin(\varphi/2)$, and γ is the Euler-Mascheroni constant (0.5772).

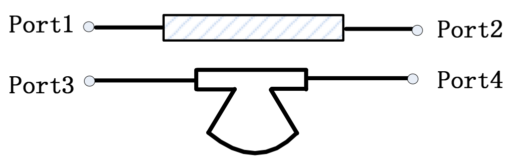


Fig. 1. The circuit configuration of the proposed phase shifter with a microstrip radial stub.

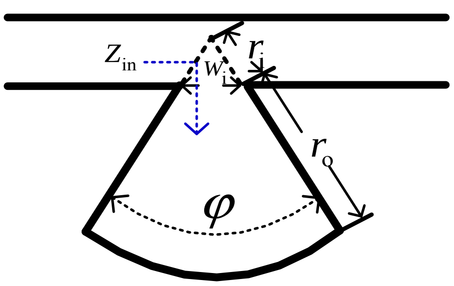
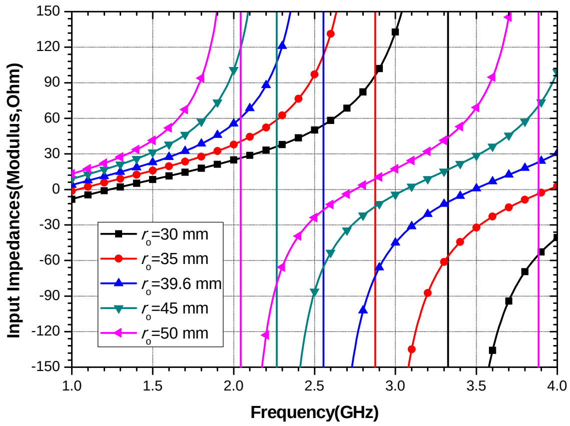


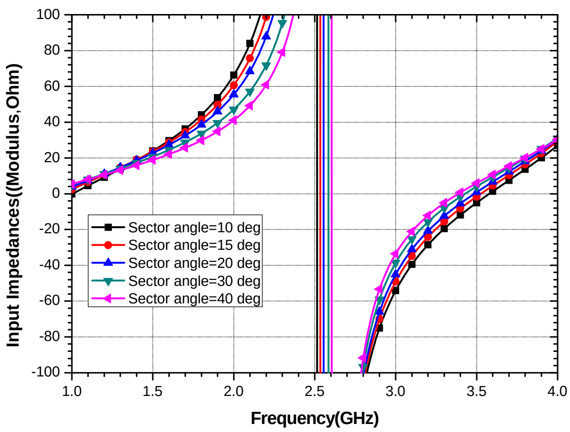
Fig. 2. Geometries and parameters of the microstrip radial stub.

From equation (1), it can be observed that the input impedance of the radial stub is decided by r_o and φ if r_i is a constant value. To simplify the calculation process, a simulation ADS tool is used to calculate the impedances of the radial stub.

Fig. 3 shows the calculated input impedances of the radial stub with different r_o and different φ. Since the input impedance of the shunt radial stub is reactance, the modulus of the input impedance values is shown in Fig. 3. From Fig. 3, we can see that the values of r_o and φ affect the input impedances of the radial stub, thereby they can affect the frequency band of the phase shifter. By selecting suitable values of r_o and φ, phase shifters with good performance can be achieved.



(a)



(b)

Fig. 3. The calculated input impedances(modulus) of the radial stub with (a) different r_o and (b) different φ.

As illustrated in Fig. 4, the radial stub with different φ causes different frequency band of the phase shifter. The smaller value of φ is, the broader band of the phase shifter can be achieved. To equalize larger bandwidth and fabrication technique, the value of φ is always not smaller than 10°.

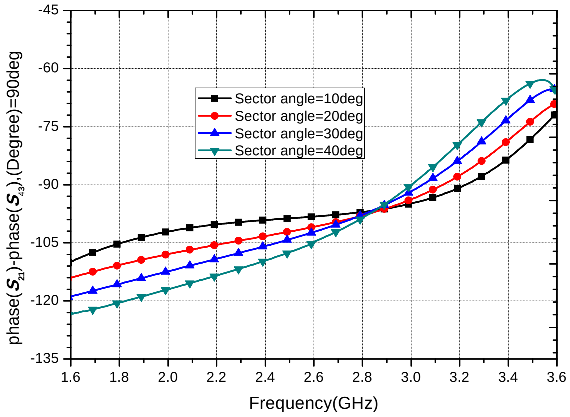
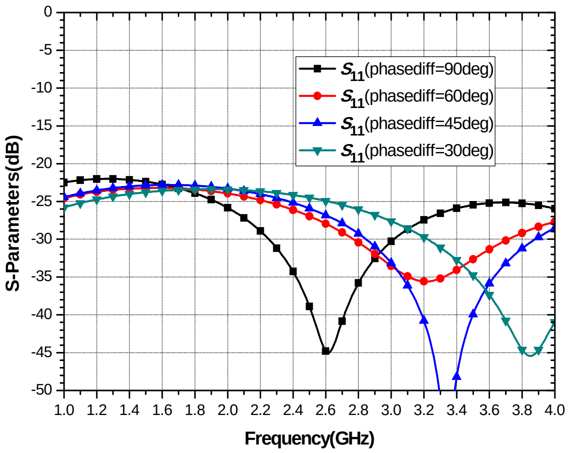
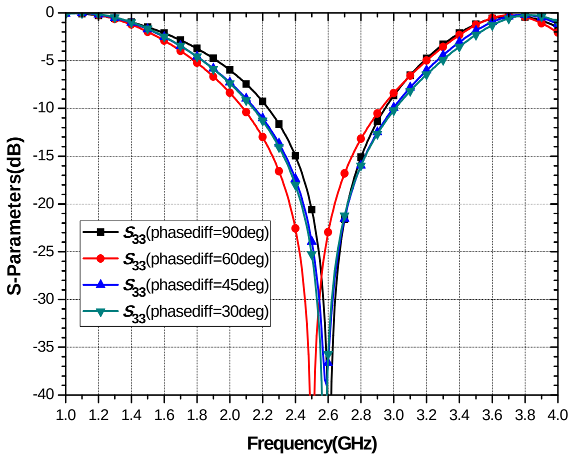


Fig. 4. The phase differences of the proposed phase shifter with different φ.

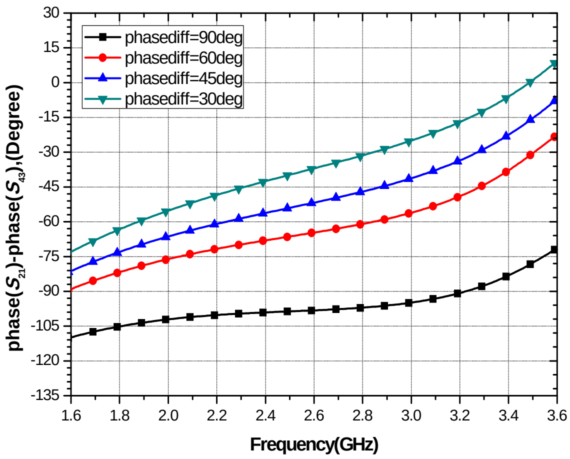
Fig. 5 presents the ideal scattering parameters and phase differences of four typical phase shifters with a radial stub of $r_o = 39.7$ mm, $\varphi = 20°$ at the frequency of 2.6 GHz. From Fig. 5, we can see that whenever the phase differences are 30°, 45°, 60° and 90°, the values of S_{11} are all below −20 dB in the whole frequency band. The center frequency of phase shifters happens at 2.8 GHz (phase-shift degrees are 30°, 45°, 60°) and 3.2 GHz (phase-shift degree is 90°) respectively shown in Fig. 5(c). Since the phase shift degree of 90°±10° is obtained across the frequency range of 2.23 GHz - 3.46 GHz (including 2.8 GHz - 3.2 GHz), the performance of the phase shifter is acceptable.



(a)



(b)



(c)

Fig. 5. The calculated results of four typical phase shifters (phase shift degree is 30°, 45°, 60°, 90° respectively) with a radial stub of $r_o = 39.7$ mm, $\varphi = 20°$: (a) scattering parameter of S_{11}, (b) scattering parameters of S_{33}, (c) phase differences.

3. Examples

To verify the proposed idea experimentally, two typical examples are designed, fabricated, and measured. The first phase shifter (A) is for 90° phase shift. The second phase shifter (B) is for 45° phase shift. F4B with a dielectric constant of 2.65 and a thickness of 1 mm is used as the substrate. The corresponding microstrip layout with defined physical parameters is determined as demonstrated in Fig. 6.

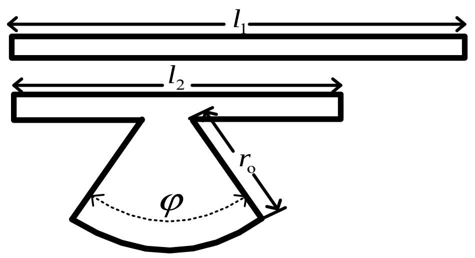


Fig. 6. The layout of the designed phase shifter.

Fig. 7 shows the photographs of the fabricated phase shifters. To demonstrate the relationship between the frequency band of the phase shifter and the angle φ of the radial stub, the value of φ is selected 20° and 10° respectively. The parameters of phase shifter A are $l_1 = 40$ mm, $l_2 = 20$ mm, $r_o = 39.6$ mm, $\varphi = 20°$. The parameters of phase shifter B are $l_1 = 30$ mm, $l_2 = 20$ mm, $r_o = 39.6$ mm, $\varphi = 10°$.

(a)

(b)

Fig. 7. The photographs of the fabricated phase shifters (a) A and (b) B.

Fig. 8 presents the simulated and measured results of the fabricated phase shifters.

From Fig. 8(b), we can get that phase shift degree of $90° \pm 10°$ is obtained across the frequency range of 2.63 - 3.38 GHz (simulated) and 2.82 - 3.51 GHz (measured). From Fig. 8(c), we can obtain that phase shift degree of $45° \pm 5°$ is obtained across the frequency range of 2.64 - 3.06 GHz (simulated) and 2.51 - 3.06 GHz (measured).

The results show that the frequency band of the fabricated phase shifter has some deviation from the simulated. Since all the values of S_{11} with phase shifter A are all below -13 dB, and the values of S_{11} with phase shifter B are all below -15 dB, the influences are acceptable in practical application. The simulated and measured results verify the availability of the proposed structure.

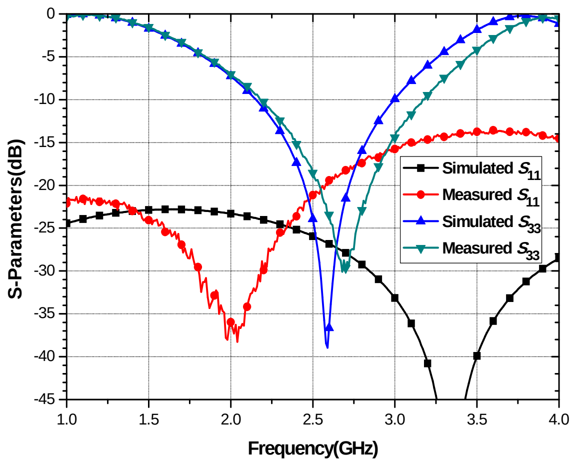


Fig. 8 (a). The simulated and measured results of the fabricated phase shifters S parameters of A.

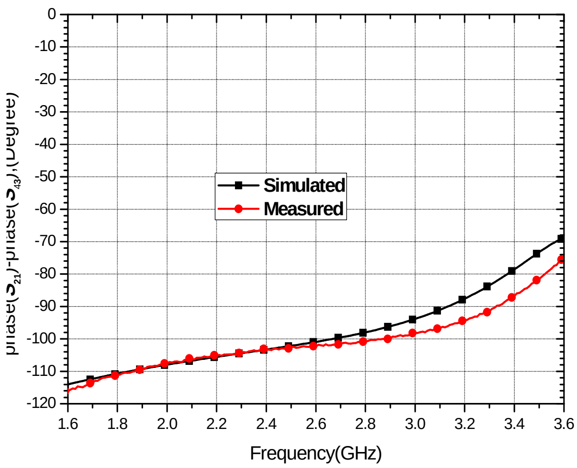


Fig. 8 (b). The simulated and measured results of the fabricated phase shifters phase difference of A.

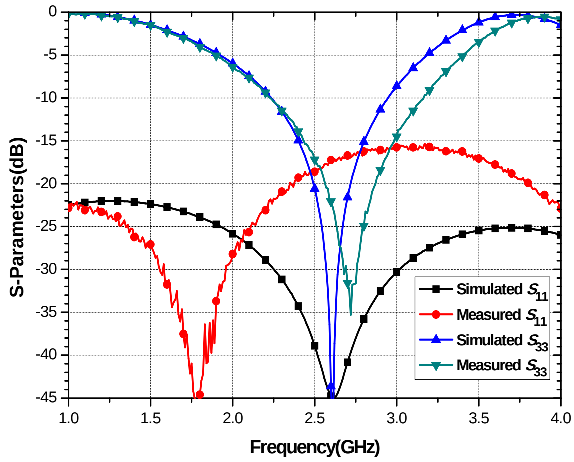


Fig. 8 (c). The simulated and measured results of the fabricated phase shifters S parameters of B.

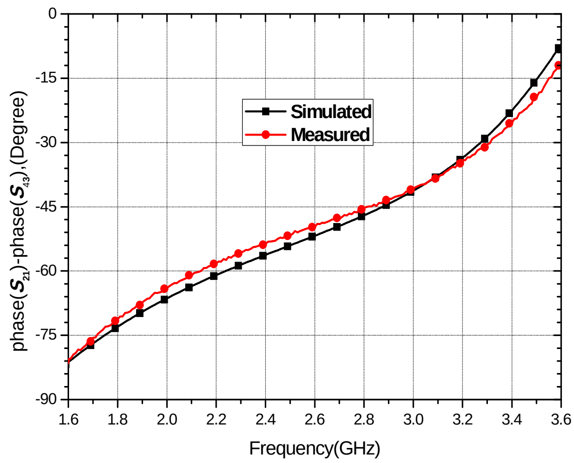


Fig. 8 (d). The simulated and measured results of the fabricated phase shifters phase difference of B.

4. Conclusions

A novel compact phase shifter with a radial stub is proposed. The proposed structure is planar and simple. The parameters which influence the input impedances of the radial stub and the frequency band of the phase shifter are analyzed. The design parameters of typical examples for phase shifters are illustrated. Two phase shifters are designed, fabricated and measured. The simulated and measured results verify the designed structure and the analysis. It is believed that the proposed structure offers an alternative where simple and planar phase shifters are required.

Acknowledgements

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