International Journal of Science and Engineering Applications
Volume 4 Issue 2, 2015, ISSN-2319-7560 (Online)

An Innovative Ultra Wideband Microstrip Phase Shifter Based on the LANGE Coupler

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Abstract: The method presented in this paper is beased on coupled line in the standard schiffman phase shifters structure and replace it with lange coupler. To having a wider bandwidth, the stronger coupling is required. One way to achieve strong coupling is using of the parallel coupled lines that this property exist in the lange coupler. So this paper discusses the design of fixed broadband phase shifter by using the lange coupler and a novel phase shifters will be introduced according to the standard schiffman phase shifters. Finally optimal parameters to achieve the desired performance will be shown.

Keywords: Standard Schiffman Phase Shifters, Lang Coupler, Phase Deviation, Coupled Lines, Microstrip Lines.

1. INTRODUCTION

Differential phase shifters are four-port passive networks that their primary function is signal phase shift between input and output ports, with a slight practical weakening (ideally zero), at a fixed frequency band.

Phase shifter known as a microwave key component and it has various applications in microwave devices and systems, modulators, power divider, radar systems (fuzzy scanning, scan delay, electronic scanning radar arrays), communication systems, microwave systems, automatic control and industrial applications, microwave radio equipment (such as wide band phased antenna arrays).

Using the coupled lines is the most common method to making the phase shifters. Best known phase shifter is standard schiffman phase shifters. But the main problem of this method is its weak coupling. On the other hand, for a bandwidth of about 80%, this phase shifter shows large phase error (±10 °) [1]. In [2], the analysis of standard schiffman phase shifters studied, also design curves is provided. In [3, 4], to achieve a wider bandwidth with acceptable phase error, edge-coupled lines approach has been used. In structures of the edge-coupled lines, the coupling coefficient depends on distance of two coupled lines as well dielectric constant in the substrate. In some cases, since dielectrics used in substrate have low relative dielectric constant, phase shifter may not work properly. So to solve this problem, the coupled lines are used with high input impedance and are connected in parallel [4]. A number of authors have proposed the use of multi-row coupled segments that many phase shifters under schiffman phase shifters has been obtained [5-12]. In [13], a wide band fixed phase shifter, 60 and 90 degrees, is designed. In [14], using a saw tooth microstrip and ground, a strong coupling is obtained. As a result, a constant phase shift of 90 degrees on a wide bandwidth is obtained. This phase shifter shows a phase difference of 90 ±°5 in 5/79 present of the bandwidth.

In general, obtaining 3 and 6 dB coupling through coupled lines is not easily achieved. One way to increase the coupling between edge-coupled lines is using multiple parallel coupled lines with each other. In this situation, the external fields on both edges of the line sides participate in the coupling. The easiest way to accomplish this situation is using the lange coupler [15].

Compared with branch-line couplers, the main advantages of lange coupler is the small size and a relatively wide bandwidth. Branch-line couplers show bandwidth of about 20%, while its substrate area is also higher. Lange coupler has low loss and wide bandwidth. It is the best option in small and compact size [16]. In this coupler, four connected coupled line is used to obtaining strong coupling. Also the coupling of 3 dB bandwidth in 1 octave is easily possible. In [17] velocity compensation of the even and odd modes in lange coupler is attempted. This compensation will help to increasing the bandwidth.

2. MODELING

Replacing coupled lines with lange coupler in standard schiffman phase shifters leads to new coupler that by connecting the two ends together, we have a new phase shifter will be called lange phase shifter. This structure is shown in Figure 1. In the Lange coupler, there are narrow coupled lines which are about a quarter wavelengths and are in parallel with each other. This way, the external fields on both sides of the lines are allowed to participate.

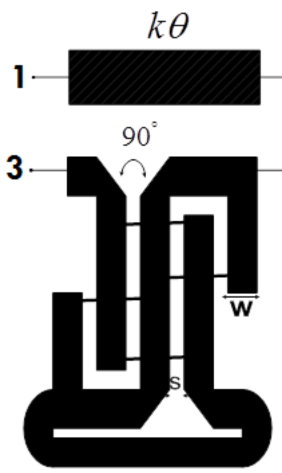

Figure 1. Structure of Lange Phase Shifter

To increase the coupling, it is necessary to use very small gaps. So coupler will have a very wide bandwidth about 1 octave. One of the disadvantages of the Lange coupler is suspended wires, which this is due to the geometric symmetry and voltage balance. Characteristic impedances in even and odd modes of the Lange coupler, based on the characteristic impedance of the line with two conductors, expressed as follows [17]:

$$Z_{e4} = Z_{0e} \frac{Z_{0e} + Z_{0o}}{3Z_{0o} + Z_{0e}} \quad (1)$$

$$Z_{o4} = Z_{0o} \frac{Z_{0e} + Z_{0o}}{3Z_{0e} + Z_{0o}} \quad (2)$$

Z_{0e} و Z_{0o} are characteristic impedances of even and odd modes, respectively. The characteristic impedance is equal to:

$$Z_0 = \sqrt{Z_{e4} Z_{o4}} = \sqrt{\frac{Z_{0e} Z_{0o} (Z_{0e} + Z_{0o})^2}{(3Z_{0e} + Z_{0o})(Z_{0e} + 3Z_{0o})}} \quad (3)$$

And coupling coefficient of voltage is equal to:

$$C = \frac{Z_{e4} - Z_{o4}}{Z_{e4} + Z_{o4}} = \frac{3(Z_{0e}{}^2 + Z_{0o}{}^2)}{3(Z_{0e}{}^2 + Z_{0o}{}^2) + 2Z_{0e} Z_{0o}} \quad (4)$$

In designing for measuring the distance between the arms, the even and odd mode impedances must be calculated. The even and odd mode characteristic impedance is a function of the characteristic impedance and coupling coefficients.

$$Z_{0e} = Z_0 \frac{4C - 3 + \sqrt{9 - 8C^2}}{2C\sqrt{1 - C/1 + C}} \quad (5)$$

$$Z_{0o} = Z_0 \frac{4C + 3 - \sqrt{9 - 8C^2}}{2C\sqrt{1 + C/1 - C}} \quad (6)$$

3. SIMULATION

In this section, to obtain the optimum performance of a phase shifter using Lange coupler, by a gradient optimization method for 6 dB Coupling, proper design parameters will be achieved. At least 3 ° phase error is defined as objective function in the fixed frequency band. In the simulation, the Duroid5880 substrate in the range 2 to 18 GHz with the specifications listed in Table 1 was used.

Table 1. Specifications of used substrate in the simulation

f_0 (GHz)	ε_r	$h(mil)$	$t(\mu m)$	$\tan\delta$
10	2.2	25	17	0.0009

Table 2. Optimized value of Lange lines parameters

Parameters	Before Optimization	After Optimization
Distance (mm)	0.548	0.521
Length (mm)	0.317	0.178
Width (mm)	5.549	5.664

Table 2 shows the optimal values, including distance, length and width of the Lange lines, which have been obtained by gradient optimization. These parameters are chosen so as to create a center frequency of 180 degrees phase. The size of proposed circuit is 15 to 25 mm. Table 3 compares the standard schiffman and Lange phase shifter. As can be seen, for coupling 3 dB, the deviation in the standard schiffman phase shifter is about 10 degrees, but in the phase shifter using the Lange coupler this amount is reduced to 5 degrees. Also the bandwidth is increased.

In figure 2, differential phase response in two phase shifter, standard schiffman and using the optimized parameters in Lange phase shifter, by the bandwidth of 7 to 13 GHz and the phase error of 3 ° is shown. Using the structure of the Lange coupler where the lines are parallel, strong coupling is obtained. And given the strong coupling, more bandwidth is obtained. Therefore, in the phase shifter using the Lange coupler, bandwidth is increased for a lesser phase error. Comparing of the phase difference from the phase shifter using Lange coupler and double schiffman phase in [4] shows differential phase response in double schiffman is asymmetric around the center frequency and bandwidth is narrower. But compared with the standard schiffman phase shifter, coupling coefficient is weaker. Other phase shifters proposed in [4] has a similar function of standard schiffman phase shifter. Differential phase response obtained is asymmetrical and narrower.

Table 3. Parameters comparison between standard schiffman and using the Lange coupler

Parameters	Using Lange Coupler	Standard Schiffman
Even mode impedance (Ω)	120.914	120.914
Odd mode impedance (Ω)	20.6759	20.6759
Characteristic impedance (Ω)	50	50
Electrical length (°)	40.1731	88.8622
Coupling coefficient (dB)	-3	-3
Phase deviation (°)	5	10
Line width (mm)	0.327649	0.718763
Line distance (mm)	0.036037	0.005566
Line length (mm)	2.54615	5.846

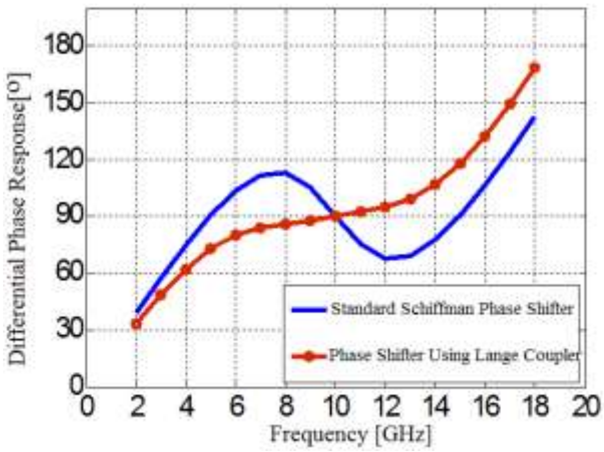

Figure 2. Comparison of differential phase response between standard schiffman and using the Lange coupler

Transmission and return loss in phase shifter using Lange coupler is compared by standard schiffman phase shifter in Figure 3 and Figure 4, respectively. As can be seen, using the

Lange coupler, transmission and return loss is much better than the coupled lines.

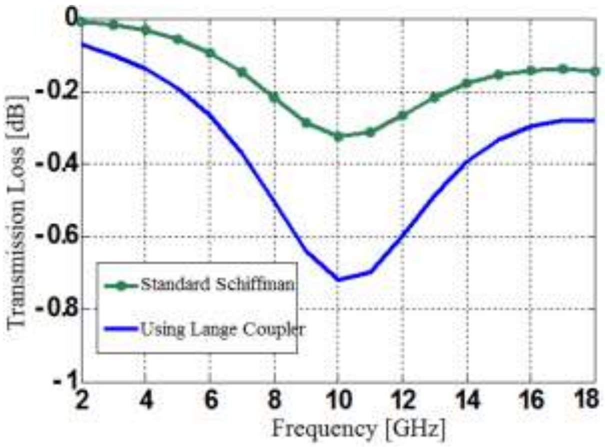

Figure. 3. Comparison of transmission loss between standard schiffman and using the Lange coupler

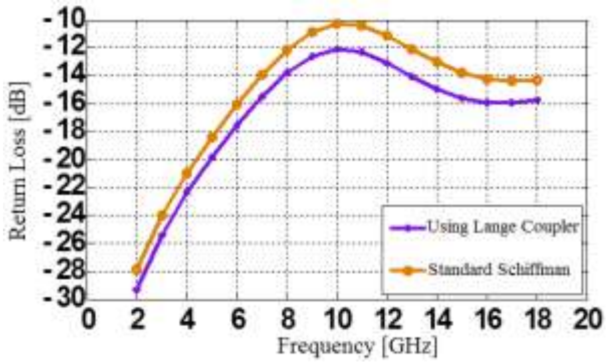

Figure. 4. Comparison of return loss between standard schiffman and using the Lange coupler

4. Conclusion

In this paper, the design problem of ultra-wideband microstrip phase shifter by using of the Lange coupler proposed. In general, to achieving strong coupling by using microstrip coupled lines in standard schiffman phase shifter is not easily achieved. Simulation results also showed that the use of a Lange coupler, in addition to creating a stronger coupling, in terms of manufacturing, it is also a much greater advantage (spacing of coupled lines to each other is further). Lange coupler caused transmission and return losses decrease about 0.4 dB in central frequency and 20%, respectively.

As suggested further research, using straight lines coupled instead of the non-uniform coupled lines caused the new more appropriate structure. The use of non-uniform line with smooth edges is not applicable. However, if internal lines changed to saw tooth, an ultra-bandwidth can be obtained.

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