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Design of Ultra-Wideband Directional Coupler Utilizing Continuous Zigzag Capacitive Compensation

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Abstract—A novel ultrawideband (UWB) coupled-line coupler with an operating frequency band from 2 to 22 GHz is presented in this article. The proposed coupler is composed of six coupled-line sections. The continuous zigzag capacitive compensation (CZCC) technology is used to broaden the operation frequency band, which also significantly enhances the isolation and return losses of the coupler. The coupler is built on a multilayer circuit structure. In order to improve the design accuracy of the three-dimensional circuit structure, the combination simulation of EM simulator and circuit simulator are employed. The simulated and measured results of the UWB 10 dB asymmetric directional coupler are presented and discussed, which demonstrate that it is practical to achieve good performances in such a circuit structure.

1. INTRODUCTION

In recent years, with the continuous development of information technology, the broadband directional coupler has been intensively investigated, which is one of the most important passive microwave circuits and has been widely used in microwave subsystems such as mixers, power splitters, and beam-forming networks [1].

For the measurement purposes, UWB directional coupler by weaker coupling is needed. The couplers are often required in the planar circuits designed by stripline or microstrip technology. For weaker coupling, compared to microstrip ones, stripline directional coupler is much easier to design. Multi-section coupled-line directional couplers are well known to broadband performance and ripple properties. There are two different groups of multi-section coupled-line directional couplers: multi-section symmetric directional coupler with 90° differential phase characteristic [2], and multi-section asymmetric directional coupler with the same performances but only half of the size of symmetric ones [3]. In order to design a high performance multi-section coupled-line directional couplers, the parasitic reactance introduced by the discontinuous connection transmission zone needs to be paid with more attention since it might lead to exasperated isolations and return losses [4]. The CZCC technology has been adopted to improve isolation and return loss performance.

In this article, the major work is to design a UWB asymmetric directional coupler and investigate the influence of parasitic reactance on the performances of UWB coupler. In order to realize UWB performance and miniaturization, the directional coupler is implemented in six-section asymmetric bias coupled-line stripline. Meanwhile, the CZCC technology has been adopted to broaden the operation band and improve the performance of the coupler. Finally, the simulated results are obtained by using the EM simulation tool. According to the simulated and measured results, it can be seen that the CZCC technology is very suitable for broadening the operating frequency band and improving the performance of directional couplers, specifically at high frequency.

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2. THE CIRCUIT ANALYSIS AND DESIGN

The geometry of the improved asymmetric 10 dB directional coupler is shown in Figure 1. The proposed structure consists of six coupled-line sections with different coupling coefficients. It brings two problem: firstly, the connecting parts between coupled-lines have many discontinuities and will deteriorate the performance of the directional coupler. Secondly, the difference in the even and odd mode phase velocities causes the degradation in directivity of the UWB couplers. Therefore, the odd-mode phase velocity should be slowed down to equal the even-mode phase velocity [5].

With uniform coupled lines several methods can be used [6, 7]. However, these techniques cannot easily be applied to nonuniform lines. Because the methods used are functions of coupling coefficient. An entirely capacitive compensation for nonuniform directional couplers using Podell's zigzag [8] line technique is presented.

The multi-section coupled-line stripline is built in a multilayer circuit, and the impedance character of the multi-section coupled-line can be divided in odd and even mode impedance which can be calculated by impedance transformation theory in [9]. The optimized matched impedance of the multi-section coupled-line can be obtained by calculating the odd and even mode impedance of multi-section coupled-line to realize the wideband impedance match through coupling between different layers. So we calculated the odd and even mode characteristic impedances so that the coupler can operate from 2 to 22 GHz with good performance. The odd and oven mode characteristic impedances as well as the electrical parameters in the directional coupler (shown in Figure 2) are listed in Table 1. Circuit dimensions of the asymmetric six-section 10 dB directional coupler can be calculated by ADS.

According to the parameter values in Table 1, the simulation models are created in ADS, and the results are shown in Figure 3.

The size of zigzag line is chosen by even and odd mode capacitance with wiggling which are related to odd and oven mode characteristic impedances, electrical length and relative permittivity. The principle was deduced in [10]. The capacitance of a zigzag calculated by EM simulator is 0.0404 pF. The width of zigzag is 0.3 mm, and its length is 0.5 mm. The phase of the zigzag capacitance is from 0° to 50°, same as the rectangle one.

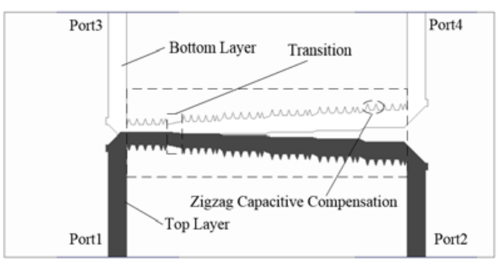

Figure 1. Middle layout of the six-section asymmetric bias stripline directional coupler with the CZCC.

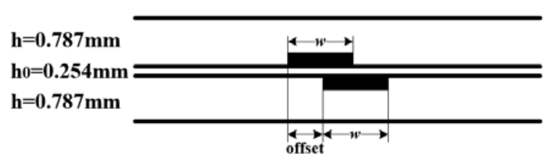

Figure 2. Cross-sectional view of the geometric structure used for the design of the proposed 10 dB directional coupler.

Table 1. Parameter of the six-section asymmetric 10-dB directional coupler.

Parameter	value	Parameter	value	Parameter	value	Parameter	value
Z_{oe1} (Ω)	87.715	Z_{oo1} (Ω)	28.501	w_1 (mm)	1.02	Offset_1 (mm)	0.6
Z_{oe2} (Ω)	74.100	Z_{oo2} (Ω)	33.738	w_2 (mm)	1.15	Offset_2 (mm)	1
Z_{oe3} (Ω)	64.790	Z_{oo3} (Ω)	38.590	w_3 (mm)	1.28	Offset_3 (mm)	1.35
Z_{oe4} (Ω)	58.520	Z_{oo4} (Ω)	42.720	w_4 (mm)	1.38	Offset_4 (mm)	1.7
Z_{oe5} (Ω)	54.435	Z_{oo5} (Ω)	45.920	w_5 (mm)	1.43	Offset_5 (mm)	2.08
Z_{oe6} (Ω)	51.915	Z_{oo6} (Ω)	48.150	w_6 (mm)	1.45	Offset_6 (mm)	2.45

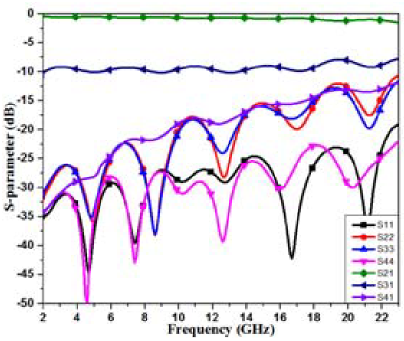

Figure 3. Simulation results of directional coupler with no CZCC.

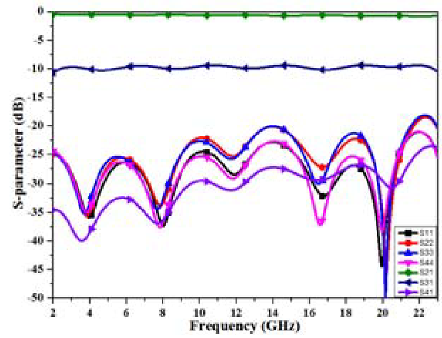

Figure 4. Simulation results of directional coupler with the CZCC.

Six zigzag capacitances are placed at every coupled-line section in order to realize a better performance. As shown in Figure 1, the zigzags are placed with equal space at the coupled-line sections. It can obtain a wider frequency band. The isolation and insertion losses are improved significantly. The operating frequency band becomes wider than theoretical prediction. Moreover, continuous zigzag capacitance can be recognized as the even characteristic impedance is changed in succession. Based on the above analysis, the simulation results of the asymmetric direction coupler used the zigzag compensation technology are shown in Figure 4. The performance of the isolation and coupling are significantly improved, especially in high frequency.

3. EXPERIMENTAL RESULTS

The presented coupler consists of four conductor layers and three substrate layers, in which the coupled-line is built on a Rogers RT 5880 substrate with the relative permittivity of 2.2 and substrate thickness of 10 mil. As shown in Figure 1, the top conductor layer includes port1 and port2, and the bottom conductor layer is similar to the top one. According to the design of couplers, the center frequency of the directional coupler is designed at 10 GHz. So the length of each section is equal to $\lambda_g/4$ (λ_g is the guided wavelength of stripline at the center frequency of 10 GHz).

A photograph of the proposed directional coupler is shown in Figure 5. Measured results of the directional coupler are shown in Figure 6. The measured isolation is better than 18 dB with the frequency band ranging from 2 to 23 GHz and approximately 7 dB worse than the simulated one. The return loss of port1 is better than 19 dB from 2 to 20 GHz. The coupling imbalance is between ± 0.8 dB. The insertion losses of the directional coupler are better than 1.4 dB. The temperature stability of a microwave device is related to the temperature character of materials inside. The expansion coefficients of the 5880

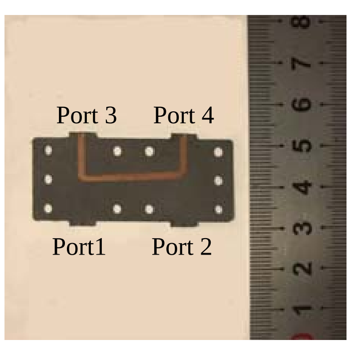

Figure 5. Photograph of the circuit.

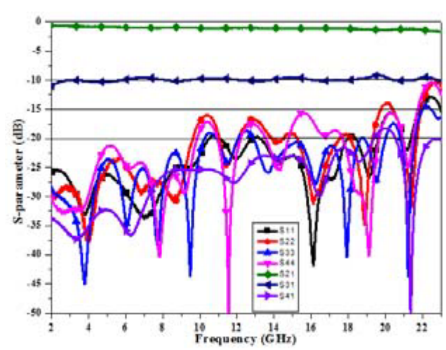

Figure 6. Measurement results of the directional coupler with the CZCC.

substrate and copper are respectively small. Therefore, the coupler can achieve a good performance from −40°C to 50°C.

It is also noticed that the measured result agrees with the simulated one. But the S parameters of test are worse at higher frequency. The deteriorations of these performances are mainly caused by two reasons. One is that the location of SMA connector on cavity has a deviation in processing position. The other is assembling error. Characteristic impedances of input and output ports change when SMA connectors are assembled. The actual characteristic impedances are not 50 Ω. It was proved by simulation that the isolation and return losses showed the same trend when the characteristic impedances was set nonstandard.

An UWB 3 dB directional coupler in stripline technology design was presented [11]. The frequency band was from 5 GHz to 19 GHz. Return loss at 19 GHz was above −15 dB. Obviously, the performance of the present design is better in the respects of frequency band and return loss.

4. CONCLUSION

An UWB asymmetric six-section coupled-line directional coupler utilizing CZCC technology is proposed in this article. The zigzag compensation capacitances in the proposed coupler are placed with equal space to broaden the bandwidth and increase the isolation of the directional coupler. The design of the coupler with equal zigzag capacitances is simpler than the one utilizing the gradient compensation capacitances. Excellent measurement results have demonstrated the advantage of the CZCC theory.

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