Reducing Crosstalk Between Microstrip Lines Using CSR Structure

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Abstract

Aiming at the problem of crosstalk between microstrip lines, a method of reducing crosstalk by using Cross-Shape Resonators (CSR) structures is proposed. On the premise of not changing the spacing of microstrip lines, this method adds CSR structures between the coupled microstrip lines to increase the capacitive coupling and thus to suppress the far-end crosstalk. Based on the analysis of the equivalent circuit of CSR structure, the parameters simulation and verification are carried out by ADS and HFSS software. Through HFSS simulation and physical test of the designed CSR structure, the results show that: the CSR structure can significantly reduce the far-end crosstalk by about 15 dB in the frequency of 0~10GHz, and the maximum can reach 43 dB. Compared with 3W crosstalk reduction method and RectangularShape Resonators (RSR) crosstalk reduction method, the crosstalk reduction effect is improved.

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Reducing Crosstalk Between Microstrip Lines Using CSR Structure†

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Aiming at the problem of crosstalk between microstrip lines, a method of reducing crosstalk by using Cross-Shape Resonators (CSR) structures is proposed. On the premise of not changing the spacing of microstrip lines, this method adds CSR structures between the coupled microstrip lines to increase the capacitive coupling and thus to suppress the far-end crosstalk. Based on the analysis of the equivalent circuit of CSR structure, the parameters simulation and verification are carried out by ADS and HFSS software. Through HFSS simulation and physical test of the designed CSR structure, the results show that: the CSR structure can significantly reduce the far-end crosstalk by about 15 dB in the frequency of 0~10GHz, and the maximum can reach 43 dB. Compared with 3W crosstalk reduction method and Rectangular-Shape Resonators (RSR) crosstalk reduction method, the crosstalk reduction effect is improved.

KEYWORDS:
crosstalk, microstrip lines, Cross-Shape Resonator (CSR)

1 | INTRODUCTION

With the continuous advancement of science and technology, people have higher requirements on the miniaturization and high performance of electronic products, resulting in the continuous compression of the wiring spacing of the interconnection transmission lines in electronic products, and the continuous increase of signal frequency, which in turn causes crosstalk that seriously interferes with signal transmission. As one of the four major signal integrity problems, crosstalk will cause signal distortion during transmission. Severe signal distortion will directly affect circuit functions, resulting in product performance degradation or even damage[1,2]. Therefore, studying the crosstalk problem between transmission lines in high-speed interconnection is an important direction to ensure the normal function of high-speed circuits, improve product performance, and promote the further development of integrated circuits.When industrial design continuously increases the operating frequency of integrated circuits to improve performance, and continuously compresses the wiring spacing of transmission lines to pursue product miniaturization, reducing crosstalk becomes an important prerequisite for ensuring correct signal transmission. Crosstalk can be divided into near-end crosstalk and far-end crosstalk. Because far-end crosstalk will seriously affect the correct judgment of the signal at the receiving end, and the damage to the circuit is more serious. Therefore, far-end crosstalk is the main factor that limits signal integrity in high-speed interconnections. One of the problems[3].

In order to avoid adverse consequences caused by excessive crosstalk, researchers have studied the factors of affecting crosstalk[4,5,6]. On the basis of the crosstalk formation principle, a method of using guard trace to reduce crosstalk is formed. Due to the simple structure of the guard trace, it has attracted extensive attention from researchers, and different forms of guard lines

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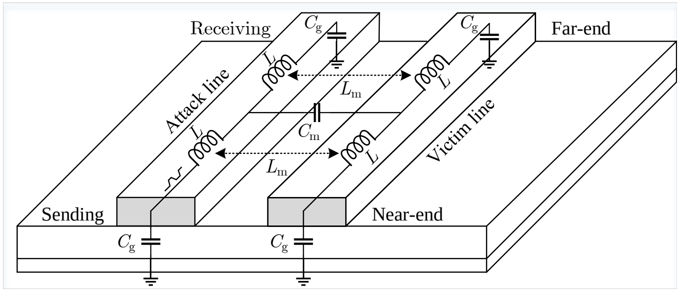


FIGURE 1 Coupled microstrip lines and equivalent circuit model.

such as serpentine guard trace and enhanced guard trace have been designed to suppress crosstalk [7,8,9]. Although the structure of the guard trace is simple, but the suppression effect of crosstalk is not good and may cause resonance problems. Some researchers have also designed a crosstalk reduction method using a mushroom-shaped dielectric structure [10], but the use of 3D printing technology increases industrial manufacturing costs, and the effect of reducing far-end crosstalk is not ideal. ased on previous research, crosstalk can be suppressed to a certain extent when the microstrip line spacing is three times the line width. Therefore, the 3W rule crosstalk reduction is generated [11]. Although this method can reduce crosstalk, it wastes limited wiring space and not suitable for circuit integration. On the basis of the crosstalk reduction method using guard trace, a Rectangular-Shaped Resonator (RSR) structure can be arranged between microstrip lines to further reduce crosstalk [12]. However, this structure has a certain crosstalk suppression effect only when the line spacing is 3W. In particular, in ensuring the effective use of wiring space, when the RSR structure is used for microstrip lines with small spacing, the effect is not ideal, and the effect of reducing crosstalk must be improved [13].

Inspired by the RSR structure, this paper designs a Cross-Shape Resonator (CSR) structure with better crosstalk reduction effect, which can further reduce the far-end crosstalk under the premise of ensuring the distance between the microstrip lines. This method is not only simple in structure and easy to implement, but it also has a good suppression effect on the far-end crosstalk within 0 10 GHz. In this paper, the proposed CSR structure is initially simulated and verified from the perspective of equivalent circuit, and then the CSR crosstalk reduction method is modeled and simulated using the three-dimensional electromagnetic simulation software High-Frequency Structure Simulator (HFSS). Furthermore, a real object is made and tested using a vector network analyzer. The effectiveness of this method is verified from the two dimensions of simulation and actual measurement.

2 | THE PRINCIPLE ANALYSIS OF CROSSTALK BETWEEN COUPLED MICROSTRIP LINES

The development and application of integrated electronic design has forced the distance between transmission lines to be greatly reduced. Therefore, when a high-speed signal is transmitted on the transmission line, the electromagnetic field generated by the transmission line can easily radiate to the adjacent transmission lines, thereby damaging the transmission quality of the signal. This harmful interference caused by electromagnetic field coupling is called crosstalk.

In high-speed interconnection, the impact of crosstalk on high-speed systems will become more significant with the reduction of transmission line spacing, and excessive crosstalk will cause wrong signal decisions, thereby affecting the normal function of system circuits. Taking two coupled microstrip lines as the object of analysis, the electromagnetic field coupling phenomenon between microstrip lines can be equivalent to mutual capacitance and mutual inductance, as shown in Figure 1. For two coupled microstrip lines, one of the transmission lines to which high-speed signals are applied is known as the attack line, and the other one that interfered with the attack line is known as the victim line. The side of the victim line close to the sending end of the attack line is known as the near end, and the side close to the receiving end of the attack line is known as the far end. Therefore, the crosstalk generated at both ends of the victim line is defined as the near-end crosstalk and far-end crosstalk respectively. The far-end crosstalk will seriously affect the correct decision of the signal at the receiver; thus, it is more important [14].

Crosstalk is due to the coupling effect caused by mutual capacitance C_m and mutual inductance C_m between the attack line and victim line. In Figure 1, when a high-speed signal is input on the attack line, the far-end crosstalk on the victim line is measured as follows [14]:

$$V_{\text{FEXT}} = \frac{1}{2} l \left(Z_0 C_{\text{m}} - \frac{L_{\text{m}}}{Z_0} \right) \cdot \frac{\mathrm{d}V_{\text{a}}(t)}{\mathrm{d}t} \tag{1}$$

Where Z_0 is the characteristic impedance of the microstrip line, l is the length of the coupling microstrip line, $V_{\text{a}}(t)$ is the input signal on the attack line, and C_{m} and L_{m} are the mutual capacitance and mutual inductance of the unit length between the attack line and victim line, respectively. As shown in Formula (1), the far-end crosstalk amplitude is proportional to the difference between C_{m} and L_{m} .Therefore, reducing the far-end crosstalk between microstrip lines can be achieved by increasing the capacitive coupling without changing the inductive coupling.

3 | CSR STRUCTURE AND CROSSTALK REDUCTION METHOD

Based on the analysis of the mechanism behind far-end crosstalk between microstrip lines, it has been determined that reducing far-end crosstalk can be achieved by increasing the capacitive coupling between microstrip lines. To achieve this, a special structure can be added between microstrip lines to increase mutual capacitance. Accordingly, this paper proposes a method to reduce crosstalk between microstrip lines by utilizing the capacitive-coupled metal resonator structure known as the CSR.The CSR structure is analyzed, which is located between two parallel-coupled microstrip lines and serves as a metal resonator. Its thickness matches the thickness of the microstrip line, and it increases mutual capacitance between microstrip lines without increasing mutual inductance. The model for arranging CSR structures at equal intervals between coupled microstrip lines is shown in Figure 2.

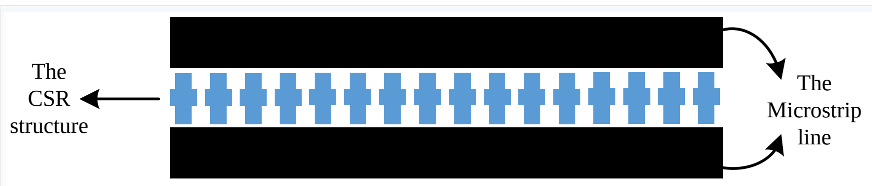


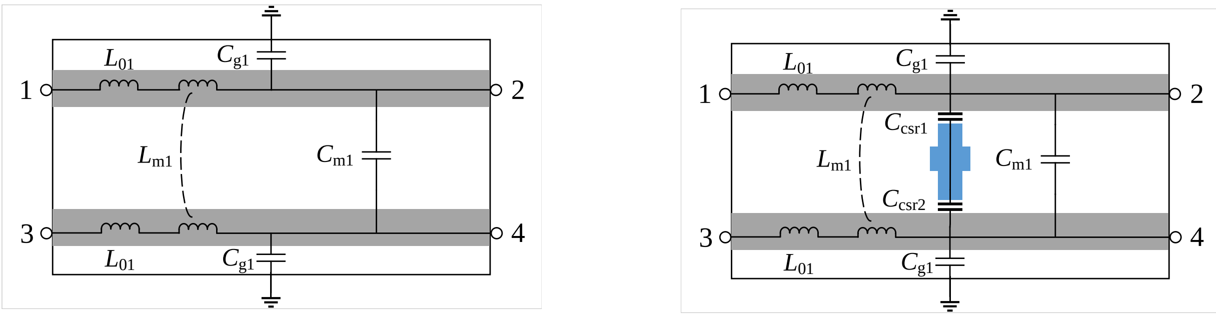
FIGURE 2 Model of the crosstalk reduction method using the CSR structure.

As shown in Figure 2, when the CSR structure is excited by the electromagnetic field generated from the attack line, the current will flow from one side of the gap to the other in the form of strong displacement current. Thus, the gap between them is equivalent to the distributed capacitance. Considering that the CSR structure is placed perpendicular to the attack line, that is, perpendicular to the direction of the magnetic field generated by the attack line, it will not increase the mutual inductance between the microstrip lines. Therefore, the CSR structure arranged between the coupled microstrip lines can be equivalent to the series connection of two capacitors[16]. The equivalent circuit is shown in Fig. 3. For better analysis, the coupling microstrip lines with a corresponding length of the CSR structure is selected as the analysis object. Figure 3 (a) shows the equivalent circuit model of the coupled microstrip lines with this length. Figure 3 (b) shows the equivalent circuit model of the coupled microstrip lines after adding the CSR structure. L_{01} represents the self-inductance of the microstrip line; L_{m1} is the mutual inductance between the two microstrip lines; C_{m1} indicates the mutual capacitance between the microstrip lines; C_{g1} represents the equivalent capacitance between the microstrip line and the reference ground, and C_{csr1} and C_{csr2} denote the distributed capacitance between the CSR structure and two microstrip lines.

Based on the equivalent circuit model, the total mutual capacitance after adding the CSR structure between the coupled microstrip lines C_{mm} is measured as follows:

$$C_{\text{mm}} = C_{\text{m1}} + \frac{C_{\text{m1}} \cdot C_{\text{m2}}}{C_{\text{m1}} + C_{\text{m2}}} \tag{2}$$

The total mutual capacitance between coupled microstrip lines increases after adding a CSR structure. Based on the calculation formula of the far-end crosstalk, this crosstalk decreases. In confirming the effectiveness of the CSR structure in reducing crosstalk, HFSS software was used to extract parasitic parameters and simulate crosstalk. The simulation model of the crosstalk



(a) (b)

FIGURE 3 Equivalent circuit of the coupled microstrip lines in two cases. (a) Coupled microstrip lines equivalent circuit model. (b) Coupled microstrip lines equivalent circuit model with a CSR structure

reduction method using the CSR structure is established through HFSS. The model consists of three parts, namely, reference ground plane, dielectric layer, and wiring layer. The specific structure is shown in Figure 4. The specific parameters of microstrip line are as follows: the line width of microstrip $w = 3$ mm, the height $m = 0.06$ mm, the distance between lines $s = 2$ mm, the thickness of the dielectric substrate $h = 1.6$ mm, the relative dielectric constant is 4.4, and the characteristic impedance of microstrip line is 50ohm.

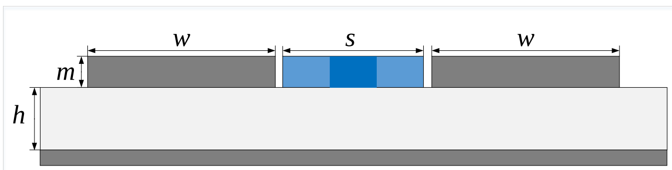


FIGURE 4 Model of the crosstalk reduction method using the CSR structure

In achieving the best crosstalk reduction effect of the CSR structure, the abovementioned model is simulated and optimized for many times, and the specific structure of CSR is determined after repeated optimization, as shown in Fig. 5. The specific parameters are as follows: $a = 0.2$ mm, $b = 0.6$ mm, $c = 0.7$ mm, $d = 0.6$ mm, $e = 0.6$ mm, $g = 0.3$ mm. The distance between the CSR structure and microstrip line is determined by the distance s and b, c, and d of the CSR structure.

In verifying the correctness of the abovementioned equivalent circuit model parameters, the Advanced Design system (ADS) was used to simulate the equivalent circuit and compare it with the HFSS simulation results. The results are shown in Fiure 6 In general, the ADS simulation results are consistent with the HFSS simulation results. Therefore, the abovementioned equivalent circuit can be used for modeling and analysis of CSR structures and methods of reducing crosstalk using CSR structure.

In addition, parasitic parameters of coupled microstrip lines with a CSR structure (Figur 6) are extracted. The extraction results are shown in Table 1. The results show that after adding a CSR structure, mutual capacitance between coupled microstrip lines increases; mutual inductance remains almost unchanged.

TABLE 1 Mutual capacitance and mutual inductance between coupled microstrip lines.

Method	L_m **(nH)**	C_m **(pF)**
Without using crosstalk reduction method	0.03052	0.11306
Crosstalk reduction method using a CSR structure	0.03052	0.12960

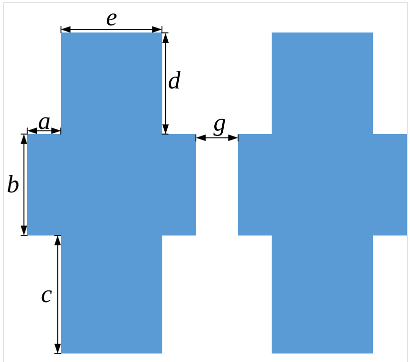


FIGURE 5 CSR structure and parameters.

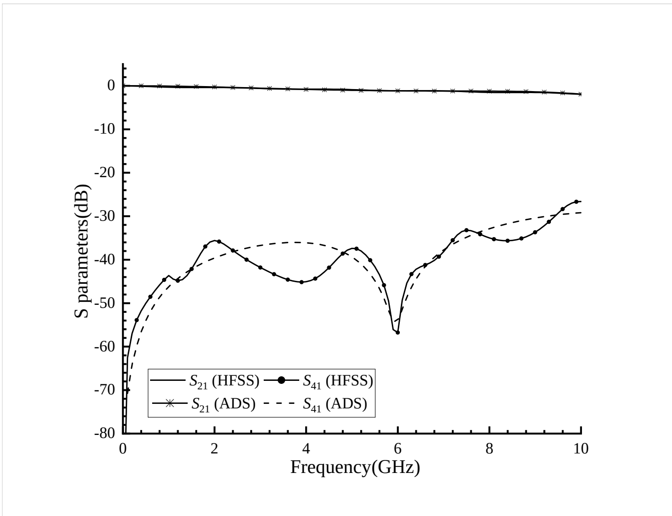


FIGURE 6 ADS simulation and HFSS simulation results.

4 | ANALYSIS OF CSR STRUCTURE DISTRIBUTION

To analyze the influence of CSR structure on the coupling phenomenon between microstrip lines, propose the CSR structure that exhibits the highest potential for reducing crosstalk, the position layout of CSR structure is simulated and analyzed. In practical applications, microstrip lines may have different lengths, making it difficult to place the CSR structure at the far end of the microstrip line. Therefore, we simulated and analyzed three different distributions of the CSR structure shown in Figure 7. Figure 7 (a) represents a scenario where as many CSR structures as possible are placed, and the CSR structure is truncated when the far end position is insufficient. Figure 7 (b) shows the scenario where the integrity of each CSR structure is maintained, and the CSR structure is placed with two equally distant ends. Finally, Figure 7 (c) shows the scenario where the far end of the microstrip line is not sufficient to place a complete CSR structure. The simulation results of the three cases are shown in Figure 8. The analysis reveals that, while the suppression effect of Case 2 on far-end crosstalk is not as significant as that of case 1, the suppression effect of Case 3 and Case 1 on far-end crosstalk is not significantly different. Therefore, for practical use of the CSR structure to reduce crosstalk, it is most effective to place it at the beginning of the transmission line to suppress far-end crosstalk. When the microstrip line ends insufficiently, it can be directly truncated, which does not significantly affect far-end crosstalk suppression, as in Case 1.

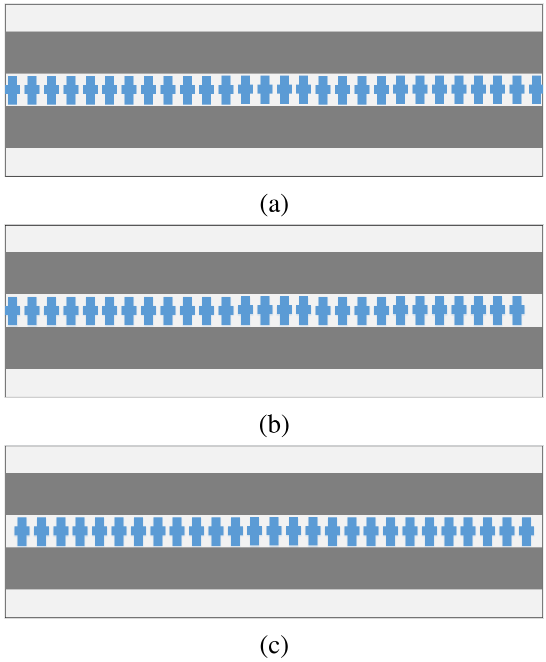


FIGURE 7 Three cases of CSR structure distribution (a) Case 1 (b) Case 2 (c) Case 3

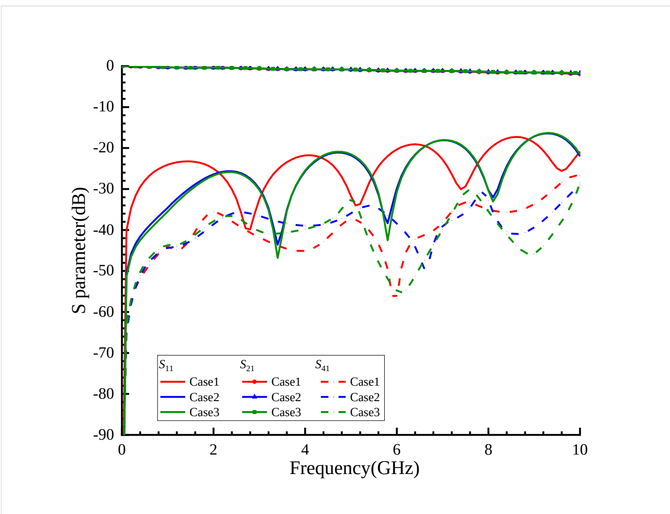
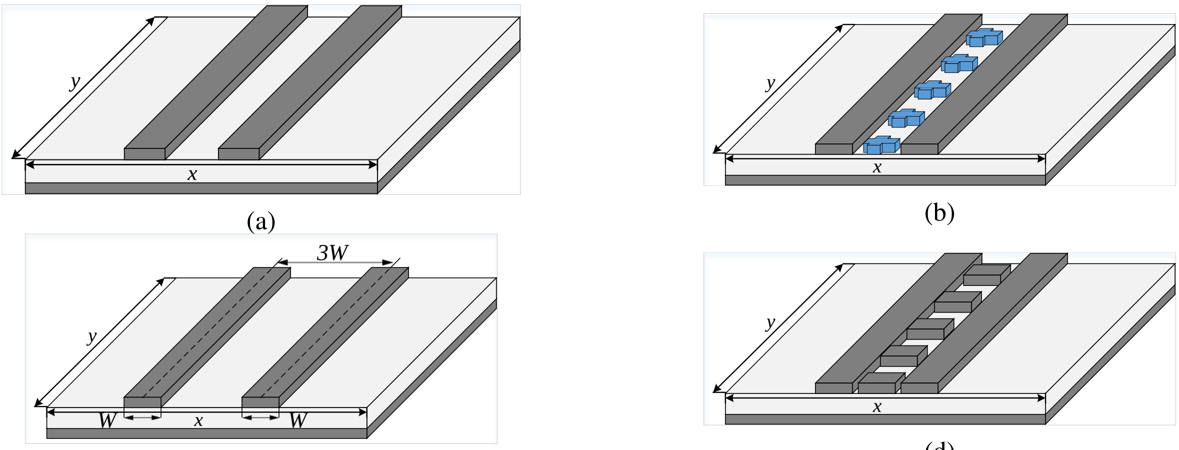


FIGURE 8 The influence of three different distributions on the coupling between microstrip lines.

5 | EXPERIMENT AND RESULT ANALYSIS

After verifying the rationality of the method at the theoretical through the equivalent circuit, this section verifies the effectiveness of the crosstalk reduction method proposed in this paper. First, use HFSS software to establish a general coupled microstrip line model with x=20mm and y=36mm, as shown in Figure 9 (a). Place the CSR structure in Figure 5 evenly between the microstrip lines. The number of CSR structures is determined by the length of the microstrip line. For CSR structures that are not completely placed, they can be directly truncated, as shown in Figure 9 (b). In order to compare the crosstalk reduction effect with other methods, the simulation models corresponding to the 3W principle crosstalk reduction method and the RSR structure crosstalk reduction method are established. The four simulation models are shown in Figure 9. Except that the line spacing in Figure 9 (c) should meet the 3W principle, the specific parameters of other microstrip lines are consistent with those shown in Figure 4.



(a) (b) (c) (d)

FIGURE 9 Four simulation analysis models (a) General coupled microstrip line (b) Method using the CSR structure (c) Method using the 3W rule (d) Method using the RSR structure

(a) (b)

FIGURE 10 Sample object: (a) S_{21} test object and (b)S_{41} test object

The S parameter simulation is carried out for the four abovementioned models. Meanwhile, the sample of the method proposed in this paper is made in accordance with the model parameters, as shown in Figure 10, and the vector network analyzer is used for measurement. The simulation and measurement results are shown in Figures 11~13. Figure 11 shows the comparison between the simulation and measurement results of the return loss (S_{11}) of the four methods in the frequency range of 0~10Ghz, and Figure 12 shows the comparison between the simulation and measurement results of the far-end crosstalk (S_{41}). Compared with the general coupled microstrip lines, the three crosstalk reduction methods can suppress the far-end crosstalk. By contrast, the crosstalk reduction method using CSR structure proposed in this paper has more advantages in suppressing far-end crosstalk, and it can reduce the far-end crosstalk by approximately 15 dB, with a maximum reduction of 43 dB. The test results are basically consistent with the simulation results, and the observed differences are primarily due to process accuracy, dielectric constantand and other factors.

Figure 13 shows the simulation and measurement results of insertion loss (S_{21}) in the four abovementioned models. Through comparison, the three crosstalk reduction methods can improve the insertion loss, but the RSR structure has limited the improvement effect on crosstalk, and the higher the frequency is, the worse the effect is. The use of a CSR structure to reduce crosstalk can improve the quality of the signals transmitted by microstrip lines, which primarily benefits from the significant improvement of the far-end crosstalk. In the abovementioned analysis, the simulation and test results show that the proposed CSR structure is better than the 3W rule and RSR structure.

6 | CONCLUSION

Based on electromagnetic coupling, this paper proposes a method to reduce crosstalk by using the CSR structure. This method adds the CSR structure to the design of coupled microstrip lines and increases capacitive coupling without changing the distance

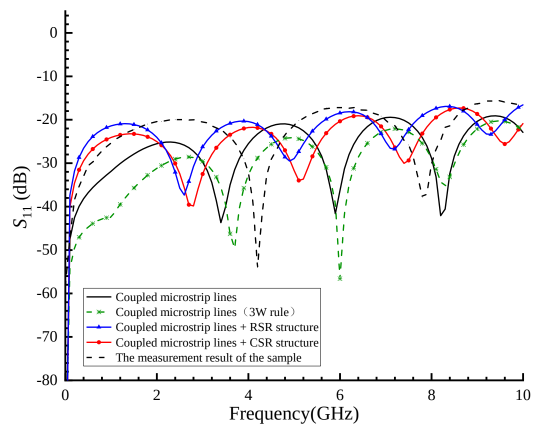


FIGURE 11 S_{11} simulation and test results.

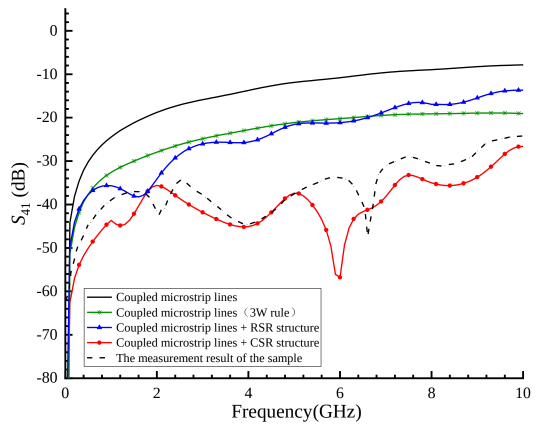


FIGURE 12 S_{41} simulation and test results.

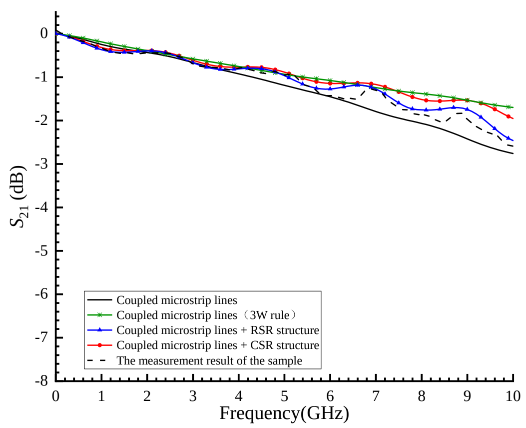


FIGURE 13 S_{21} simulation and test results.

between coupled microstrip lines, thereby reducing the far-end crosstalk. Software simulation and actual measurement show that this method can effectively reduce the crosstalk. Compared with the 3W rule and RSR structure, the crosstalk reduction effect is better, which shows great application potential.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

CONFLICT OF INTEREST

All authors declared that they have no conflict of interest relevant to this article.

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