Crosstalk Reduction between Microstrip Lines using TL-Shaped Defected Microstrip Structure

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Abstract

A method to reduce crosstalk using TL-shaped defect microstrip structure (DMS) is proposed to solve the far-end crosstalk between microstrip lines. This method optimizes the ratio of the capacitive coupling and the inductive coupling between the coupled microstrip lines by etching the TL-shaped DMS on the microstrip line and reduces the strength of the electromagnetic (EM) coupling, which can achieve crosstalk suppression. The equivalent circuit model, S-parameters and full-wave EM simulations are used to analyze the crosstalk between the microstrip lines etched with and without the TL-shaped DMS. High Frequency Structure Simulator (HFSS) software simulation and samples test results show that the TL-shaped DMS can effectively reduce the far-end crosstalk while guaranteeing the transmission ability of microstrip line to the signal. The maximum far-end crosstalk can be reduced by 42dB in the frequency range of 0–8 GHz and the test results of the samples are in good agreement with the simulation results.

Crosstalk Reduction between Microstrip Lines using TL-Shaped Defected Microstrip Structure

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INTRODUCTION

Integrated circuits have been widely used with the rapid development of industrial technology and the continuous increase in people's demand for electronic products. As a necessary interconnection structure in integrated circuits, the crosstalk has become an important factor restricting the further development of integrated circuits. Therefore, the effect of crosstalk between coupled microstrip lines on integrated circuits must be investigated.

The spacing between the microstrip lines is extremely small due to the high integration requirements of integrated circuits and is easy to cause EM coupling between the microstrip lines, thereby forming crosstalk [1]. To adapt to the development trend of integrated circuits, research scholars at home and abroad have explored methods to reduce crosstalk. They analyze the formation principles and influencing factors of crosstalk between two or more transmission lines [2] and use them as the theoretical basis to develop methods for reducing crosstalk. In accordance with the principle of crosstalk formation, further analysis shows that increasing the transmission line spacing is an effective method to reduce crosstalk [3]. Although this method has better ability to suppress crosstalk, it wastes considerable limited wiring space and does not conform to the development direction of integration. In [4,5,6], the crosstalk is reduced by placing a via-stitch guard or a serpentine guard trace between multiple transmission lines, and the effect of crosstalk suppression is analyzed by EM simulation. Although it has a certain suppression effect on the crosstalk, it affects the wiring method to a certain extent. Resonance problems may also occur. In actual application, the protection line needs to be analyzed and designed separately, which increases the design cost, does not have wide applicability, and is difficult to promote. In [7], the microstrip line structure is covered with a graphene coating, and the crosstalk is reduced by depositing a covering dielectric layer. This method causes the transmission power to be absorbed by the coating to a certain extent, and the use of graphene deposition layers requires higher production costs. In [8,9,10], the method of changing the physical form of the transmission line by inserting rectangular slots for the transmission line or using steeped transmission line is used to reduce the crosstalk. The essence is to reduce the crosstalk by changing the capacitive coupling and inductive coupling ratio. The disadvantage of this method is that the far-end crosstalk reduction effect is not ideal, and the maximum crosstalk suppression effect is only 6 dB for some stepped structures. In [11], a specific DMS is etched on the microstrip line to achieve crosstalk reduction. However, this S-shaped structure design is extremely complicated, the etching is extremely difficult, and the crosstalk suppression effect is limited.

On the basis of the DMS research of [11], this paper designs a TL-shaped DMS, which has a simple structure and is easy to apply in practice. The TL-shaped DMS has a better suppression effect on the far-end crosstalk in the 0–8 GHz frequency band while improving the insertion loss of adjacent microstrip lines, and guaranteeing the signal transmission performance of its own microstrip lines compared with the S-shaped DMS. The proposed method is simulated and verified through theoretical analysis and full-wave EM simulation, using HFSS (a full wave 3-D EM Simulation tool from Ansoft Corporation). Compared with the ordinary coupled microstrip line that does not use this method, the effect of this method on crosstalk suppression is quantified, and its effectiveness is proved. The comparison of measured results of samples and simulation results shows that they are in good agreement, indicating that the proposed method has practical application value and good results.

ANALYSIS OF CROSSTALK BETWEEN COUPLED MICROSTRIP LINES

With the development of integration, the wiring space is becoming increasingly limited, resulting in the continuous reduction of the distance between transmission lines. For two or more transmission lines arranged adjacent to each other, when one of the transmission lines is transmitting signals, it will cause harmful interference to the adjacent transmission lines. This harmful interference caused by the coupling of transmission lines is called coupling crosstalk. The transmission line which transmits the signal is usually called the attack line, and the transmission line with degraded signal transmission quality due to the crosstalk generated by the attack line is called the victim line.

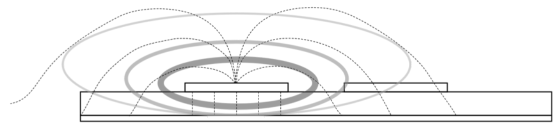


Figure 1 Coupled microstrip line in an EM field

Taking two parallel microstrip lines as an example, the attack line will generate electric and magnetic fields when transmitting signals, as shown in Figure 1. The electric field and magnetic field generated by the attack line can easily radiate to the adjacent microstrip line because the distance between the two microstrip lines is extremely small. Therefore, there will be a large crosstalk on the victim line, which is the direct cause of crosstalk. Two parallel coupled microstrip lines are designed as the basic model to analyze the crosstalk in detail and the methods of restraining crosstalk and ensuring transmission signal are explored. The specific structure is shown in Figure 2.

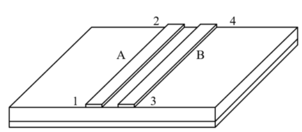


Figure 2 Coupled microstrip line structure

A model is established in accordance with the structure shown in Figure 2. An excitation signal is added to port 1, microstrip line A is regarded as an attack line, and the adjacent microstrip line B as a victim line. For the convenience of analysis, only the crosstalk caused by the attack line to the victim line is considered, and the secondary crosstalk is ignored. At this time, the crosstalk generated from the attack line port 1 to the victim line port 4 can be expressed as [13]

$$V_{\text{fext}} = \frac{1}{2}\left(\frac{C_m}{C_T} - \frac{L_m}{L_S}\right) \cdot TD \cdot \frac{V_m}{T_r} \# (1)$$

where TD is the time for the signal to pass through the transmission line, V_m is the signal amplitude, and T_r is the rising edge time. When the input signal propagates along the attack line, it will form mutual capacitance and mutual inductance with the victim line, which is recorded asC_m and L_m. the crosstalk received by the end of the victim line away from the input port is the far-end crosstalk, denoted asV_{fext}; C_T represents the sum of mutual capacitance and self-capacitance between the transmission lines, and $L_S$represents the self-inductance of the transmission line. Equation (1) shows that from the circuit point of view, changing the ratio of the capacitive coupling and the inductive coupling between the coupled microstrip lines is the most direct and effective means to change the size of the crosstalk without changing the rise time of the transmission signal and signal amplitude.

TL-SHAPED DMS METHOD TO REDUCE CROSSTALK

In accordance with the above theoretical analysis of the far-end crosstalk, it shows that the coupling EM field between microstrip lines can reflect the crosstalk, and that the far-end crosstalk can be suppressed by increasing the coupling capacitance between transmission lines. DMS can be equivalent to an LC parallel circuit [11], as shown in Figure 3. The equivalent circuit model of the etched DMS coupled microstrip line can be further analyzed by a single DMS equivalent circuit, as shown in Figure 4.

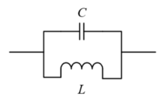


Figure 3 Equivalent circuit of a single DMS structure

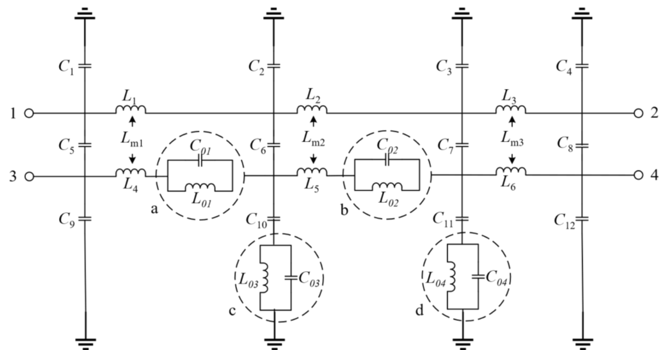
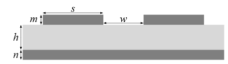


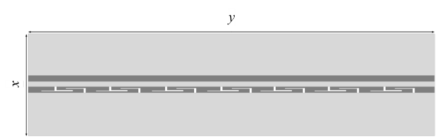
Figure 4 Microstrip line equivalent circuit of etched TL-shaped DMS structure

In Figure 4, C_1, C_2,C_3, C_4 andC_9, C_{10},C_{11}, C_{12} are the equivalent capacitances between the transmission line and the reference ground, C_5, C_6,C_7, C_8 are the coupling capacitances between the two coupled transmission lines,L_1, L_2,L_3 and L_4,L_5, L_6 are the inductances of the transmission line, and L_{m1},L_{m2}, and L_{m3} are the coupled inductances. Structure a and structure b are equivalent circuit structures of the TL-shaped DMS. Structures c and d must be designed because the DMS structure changes the current distribution on the microstrip line, which affects the reference ground. According to the analysis of the equivalent circuit, the etching DMS can change the ratio of the capacitive coupling and the inductive coupling between the coupled microstrip lines, that is, C_m/C_T and L_m/L_Tin Equation (1), thereby reducing the far-end crosstalkV_{fext}.

Based on the above analysis, an excellent DMS structure design can have a good ability to suppress far-end crosstalk by clever design, therefore, the TL-shaped DMS is etched on the microstrip line B. The specific structure model is shown in Figure 5. Figures 5(a) and (b) show the top view and left view of the model.



(a)



(b)

Figure 5 Etched TL-shaped DMS coupled microstrip line model (a) Side view (b) Top view

SIMULATION ANALYSIS AND PHYSICAL TEST

The designed TL-shaped DMS method to reduce crosstalk is simulated for multiple times, verified, and optimized on HFSS software. A three-layer PCB board model with length x =80 mm and width y =20 mm is designed in this paper, at the same time, no solder mask coating is added to explore the actual situation of crosstalk between microstrip lines. In order to ensure that the characteristic impedance of the microstrip line is 50 Ω, the specific parameters of the microstrip line are designed as follows: microstrip line width s =1.2 mm, microstrip line height m =0.06 mm, microstrip line spacing w =1 mm, the material of the dielectric layer is widely used FR4 material, the dielectric constant is set to 4.4, the thickness of the dielectric layer is h =0.8 mm, and the reference strata thickness is n =0.2 mm. To compare DMS designs with the best crosstalk suppression capabilities, a three-layer PCB model using a common coupled microstrip line is set as the control group. The TL-shaped DMS is composed of T-shaped and L-shaped structures, as shown in Figure 6. The design parameters of the TL-shaped DMS through simulation optimization are as follows: a =0.4 mm, b =4.1 mm, c =0.4 mm, d =0.8 mm, e =0.2 mm, f =0.1 mm, g =6.7 mm, p =0.1 mm, k =0.8 mm.

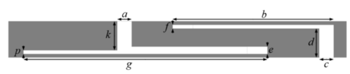
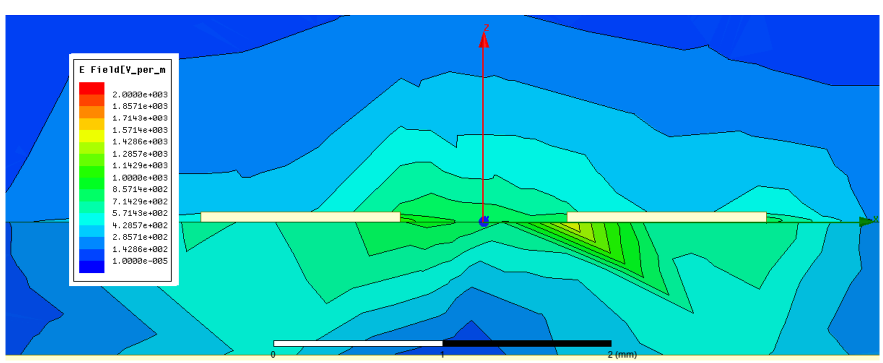


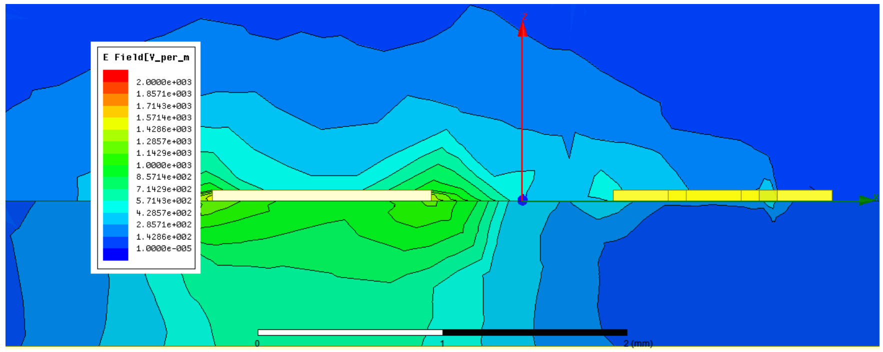
Figure 6 TL-shaped DMS structure and its parameters

SIMULATION AND ANALYSIS OF EM

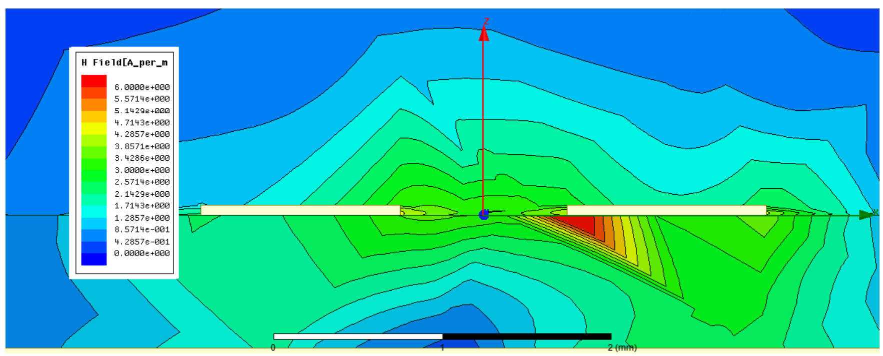
Crosstalk is mainly caused by the EM field radiated by the attack line to the space around the injured line, which produces the disturbing current on the injured line. In accordance with the defect ground structure (DGS), the proposed DMS is a periodic or aperiodic defect structure that is etched on the transmission line [14]. When some metals are removed from the microstrip line according to the designed DMS shape, the loss of this part will change the EM distribution between the coupled microstrip lines and affect the coupling crosstalk. The ability of DMS to suppress crosstalk can be judged by EM simulation,therefore, in order to analyze the effect of TL-shaped DMS to suppress crosstalk between coupled microstrip lines, the full-wave EM simulation of the above model is carried out, and the simulation results are shown in Figure 7.



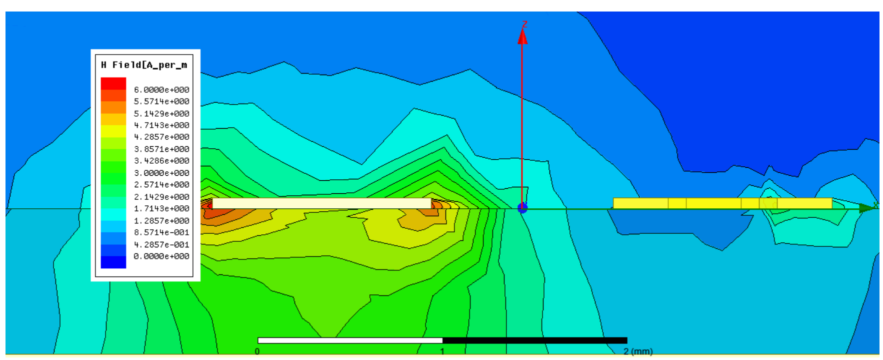
(a)



(b)



(c)



(d)

Figure 7 EM fields lines and magnitudes of the coupled microstrip lines with and without TL-shaped DMS: (a) electrical field lines and magnitudes of the coupled microstrip lines without TL-shaped DMS, (b) electrical field lines and magnitudes of the coupled microstrip lines with TL-shaped DMS, (c) magnetic field lines and magnitudes of the coupled microstrip lines without TL-shaped DMS, (d) magnetic field lines and magnitudes of the coupled microstrip lines with TL-shaped DMS

Compared with the simulation results of EM in Figure 7, the electric field and magnetic field intensity in the space near the microstrip line etched with TL-shaped DMS structure are decreased. It can be concluded that the etching of TL-shaped DMS structure on microstrip line can reduce the EM flux through the damaged line by changing the current path, therefore, the TL-shaped DMS can reduce crosstalk by restraining EM coupling.

SIMULATION AND TEST OF S-PARAMETERS

In order to verify and quantify the effect of TL-shaped DMS structure on the transmission ability of microstrip line and the effect of crosstalk suppression, S-parameters simulation was carried out by using HFSS software, and make a real object to test with the vector network analyzer (VNA). Because the distance between the microstrip lines is too small to place the connectors at the same time, the three samples are made and tested respectively, two ports are placed on the connectors, the other two ports are connected to a high-precision 50 Ω resistor before grounding to ensure test accuracy. The fabricated samples are shown in Figures 8, 9 and 10.

Figure 8 Fabricated sample of measuring the insertion loss (S21)

Figure 9 Fabricated sample of measuring the insertion loss (S43) and the return loss (S33)

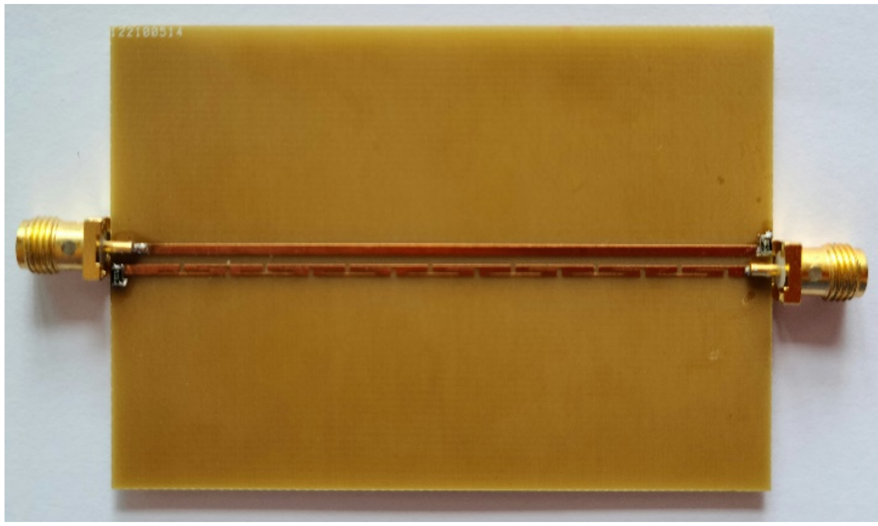


Figure10 Fabricated sample of measuring the far-end crosstalk (S41)

The results of HFSS simulation and physical test are shown in Figures 11 and 12 respectively. Figure 11 shows the magnitude of far-end crosstalk between coupled microstrip lines. The far-end crosstalk between microstrip lines is significantly smaller after etching TL-shaped DMS, and TL-shaped DMS has excellent ability to suppress far-end crosstalk. Therefore, TL-shaped DMS in the 0-8GHz band can effectively suppress the far-end crosstalk between coupled microstrip lines, and the maximum reduction of the far-end crosstalk between coupled microstrip lines can reach 42dB. There is a slight deviation between the simulation results and the test results, which is mainly caused by the error of the dielectric constant of the samples, but the trend of two results are almost identical. The crosstalk reduction method based on the TL-shaped DMS is compared with other crosstalk reduction methods using DMS, and the results are shown in Table 1. It can be seen that the TL-shaped DMS adopted in this paper is most effective in suppressing far-end crosstalk under the condition of relatively simple structure.

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Figure 11 The simulated and measured results for S41 of the coupled microstrip lines with and without TL-shaped DMS

Table 1 Comparison of crosstalk suppression effects of different DMSs

DMS	Simulation bandwidth	Far-end crosstalk suppression effect
S-shaped DMS [11]	0–12 GHz	Maximum of approximately 30 dB
T-shaped DMS [15]	0–10GHz	Maximum of approximately 35 dB
Irregular-shaped DMS [16]	0–12 GHz	Maximum of approximately 24 dB
G-shaped DMS and stepped structure [17]	1–8 GHz	Maximum of approximately 20 dB
TL-shaped DMS	0–8 GHz	Maximum of approximately 42 dB

The insertion loss and return loss of the coupled microstrip lines with and without TL-shaped DMS are compared in Figure 12. By comparing the results of simulation and measurement at the frequency of 0–8

GHz, it is found that the insertion loss of etching TL-shaped DMS microstrip lines and its adjacent microstrip line is better than unetched TL-shaped DMS microstrip line, which proves that etch TL-shaped DMS can improve the signal transmission ability of two adjacent coupled microstrip lines and this is mainly due to the benefits of the suppression of far-end crosstalk. The results of physical test and simulation cannot match completely, which is mainly due to the accuracy of physical production and unavoidable error of VNA, but the general trend is the same.

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Figure 12 The simulated and measured results for S33 and S43 of the coupled microstrip lines with and without TL-shaped DMS

CONCLUSION

This paper proposes a method to reduce far-end crosstalk based on TL-shaped DMS. This method designs a TL-shaped DMS with a relatively simple structure and easy practical application. Under the joint verification of theoretical analysis, simulation verification, and physical test, TL-shaped DMS can improve the insertion loss of adjacent microstrip lines while ensuring the transmission ability of the etched microstrip lines, and the far-end crosstalk can be well suppressed with a maximum reduction of 42dB. Compared with other methods, The TL-shaped DMS proposed in this paper has a simple design structure, does not occupy the original wiring space, has the potential for universal application, and far-end crosstalk was suppressed more significantly. However, its promotion and application in a wide range need further research.

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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