Using Rectangular-Shape Resonators to Improve the Far-End Crosstalk of the Coupled Microstrip Lines

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Abstract - Modern electronic products must have high-speed, high-density layout, small size, faster rising time and lower voltages supply. With such design, signal integrity (SI) becomes a very important factor because sensitive equipment is affected by electromagnetic interference (EMI) and noise interference. Crosstalk is a major factor in SI from printed circuit boards (PCBs). Crosstalk noise is usually represented in terms of near-end crosstalk (NEXT) and far-end crosstalk (FEXT). In order to cost concerns, microstrip line is widely used for PCBs because it’s easy to manufacture. In microstrip line structure, FEXT is induced by the difference between the capacitive coupling ratio ($C_m/C_T$) and inductive coupling ratio ($L_m/L_S$). In earlier research, however, many researchers had proposed solutions that are guard trace which are used to reduce NEXT and FEXT. Since a large number of shorting-via degrades the SI and reduces the flexibility of the circuit routing. Another technique to reduce the FEXT noise is serpentine guard trace, but this kind of guard trace requires to be terminated with matched resistances at both ends of guard trace. In this paper, we propose a method to reduce the far-end crosstalk by using rectangular-shape resonators (RSR) structure. In which, the shorting-via and resistance are not necessary to be used for improving the FEXT. The frequency-domain simulation of HFSS shows that the $S_{41}$ of RSR structure is decreased more than 7 dB compared to the 3-W rule. The time-domain simulation of ADS shows that the peak of far-end crosstalk voltage of RSR structure is improved to 54% compared to the 3-W rule.

1. INTRODUCTION

In the modern generation of high information processing, electronic products must have high-speed, high-density layout, small size, faster rising time and lower voltages supply. With such designs, the signal integrity (SI) problem in a poor printed circuit board layout is affected by noise. SI is a critical factor in the design of a high-speed PCB [1]. Crosstalk is one noise source in PCBs and is of particular concern in high-density and high-speed circuits, is one major source of noise to interfere with SI. In recent years, the crosstalk noise problem is getting worse because layout density is increasing between connections of chips. Crosstalk noise is usually represented in terms of near-end crosstalk (NEXT) and far-end crosstalk (FEXT). FEXT is induced by the different of the inductive coupling ratio and capacitive coupling ratio, but in addition, it is proportional to the length of the parallel transmission lines and only exists in inhomogeneous environment, e.g., the microstrip structure [2]. In a parallel-terminated interface, the FEXT is more problematic than NEXT since it seriously affects the SI at the receiver side [3]. Therefore, decreasing FEXT is one of the most important goals in a PCB design.
In general, the electronic devices in order to prevent crosstalk interference are to be designed to three times the transmission line width, where the rules known as the 3W [4]. The general method most commonly were to add guard trace structure between two coupled traces that the active trace to which the signal is applied is called the aggressor line, the passive trace to which no signal is applied is called the victim line. However, a guard trace is also a potential noise source because it is to like transmission line of open terminated [5]. In practice, guard trace with a lot of shorting-vias should be added to maintain a stable grounded potential. In a real layout, however, only a few plated vias can be used to connect the guard trace and ground plane due to circuit backside routing restriction [2][6].

In this paper, we propose a method to reduce effectively the FEXT by using rectangular-shape resonators (RSR) structure. In which, the shorting-via and resistance are not necessary for improving the FEXT noise. Hence, compared to past method mentioned above, the proposed method own the advantage of the flexibility of the circuit backside routing.

2. FAR-END CROSSTALK

Crosstalk occurs due to the coupling effects caused by the mutual capacitance ($C_m$) and mutual inductance ($L_m$) of the victim and aggressor, driven by the transient signals in the aggressor. Crosstalk noise is usually represented in terms of NEXT and FEXT. The equivalent model of the two parallel traces is shown in Fig. 1(a), and the typical crosstalk signature of the victim without a guard trace is shown in Fig.1 [1]. The end of the victim closest to the driver (receiver) of the aggressor is called the near (far) end. When the rise and fall times of the aggressor’s transient logic states change continually, the signal operation of the victim will be destroyed, since the coupling effect of $C_m$ and $L_m$ transfer energy from the aggressor [9]. Since modern high-speed circuits have intensive of wiring layout caused by high $C_m$ and $L_m$, crosstalk noise is a major issue in high-speed digital system design. In some cases, e.g., microstrip line, the inductive coupling ratio is always larger than capacitive coupling ratio because the dielectric constant of surrounding air is less than that of the PCB dielectric material [7]. This difference between inductive and capacitive coupling ratios can induce FEXT. Let $L_S$ and $C_S$ be the self-inductance and self-capacitance, respectively. The FEXT can be represented as [8]

$$V_{\text{FEXT}} = -\frac{V_{\text{in}}}{2T_r} \cdot TD \cdot \left( \frac{L_m}{L_S} - \frac{C_m}{C_T} \right)$$

where $V_{\text{in}}$ is the input voltage, $TD$ is the time delay and $T_r$ is the rising time.

Fig. 1. (a) Equivalent model of the two parallel traces [8]. (b) Typical crosstalk signature of the victim without a guard trace [1].
Based on Eq. (1), how to get lower difference of the inductive coupling and capacitive coupling is necessary to decrease FEXT.

3. RECTANGULAR-SHAPE RESONATORS STRUCTURE

In the following analysis structure which is placed on FR4 PCB substrate. Dielectric constant of the substrate is 4.4 and thickness is 1.6 mm. The thickness of copper (trace and ground) is 0.035 mm. The width of the microstrip line is designed to 3 mm to match 50 Ω. The length of trace is 50 mm. Fig. 2 (a), (b) and (c) represent the three structures, 3-W rule, shorting-via guard trace and RSR structure, respectively. For the fair comparison, all of the above layout parameters are the same among these three approaches. In Fig. 2(b), we used seven shorting-vias to enhance FEXT, and distance between vias is 7.8 mm. Based on [10], between the two vias the resonant frequency can be determined. In the guard trace of seven shorting-vias, we can move the first resonant frequency of the bandwidth in interested frequency range.

Although shorting-via guard trace can reduce FEXT which takes a lot of via hole connected to the ground plane. In practice, however, we can't use a lot of via hole by circuit routing restriction [2][5]. In this concerns of circuit backside routing restriction, the RSR structure is used to improve FEXT as Fig. 2(c), where \( l_r = 8 \) mm and \( W_r = 1 \) mm. In this method, it needn’t use any shorting-via and resistance connected to ground plane. In order to compare the convenience, we use eleven RSR structure to reduce the FEXT. In practice, we can add more RSR structure to improve the FEXT because it does not need to use shorting-via.

![Fig. 2. Comparison among three topologies. (a) 3-W Rule (b) shorting-via guard trace (c) RSR structure.](image)

4. SIMULATION AND COMPARISON

Fig. 2(a), (b) and (c) show the comparison of the three cases as 3-W, shorting-via guard trace and RSR structure, respectively. The parameter setup is the same as that in Fig. 2 and section 3. In this work,
frequency-domain simulation is based on using the field solver High Frequency Structure Simulator (HFSS) [11] and FEKO [12]. Comparison of three kinds of structure, the shorting-via guard trace and RSR are better than the 3-W rule. But in RSR structure, where needn’t use shorting-via to enhance the FEXT. RSR structure can enhance 7 dB and 3dB for 3W and shorting-via structure. In Fig. 4, the time-domain simulation of Advanced Design System (ADS) shows that the peak of far-end crosstalk voltage of RSR structure is improved to 54% of that of 3-W rule, where input voltages is 1 V and rising time is 100 ps.

Fig. 3. Comparison of frequency-domain simulation.

Fig. 4. Comparison of time-domain simulation.
5. CONCLUSIONS

Verified in the frequency-domain simulation results, our approach of the rectangular-shape resonators structure can enhance far-end crosstalk by 7 and 3 dB compared to the three times of width rule and the shorting-via guard trace, respectively. In time-domain simulation, the rectangular-shape resonators structure can decrease 54% and 30% compared to the 3-W rule and the shorting-via guard trace, respectively. All results are showing that the proposed structure has a very good performance among these three approaches. In this method, it can reduce the FEXT, where needn’t use shorting-via and resistance to enhance the FEXT noise. Hence, our method can be indeed employed to those products of the high-speed printed circuit board applications to suppress the far-end crosstalk and then increase their reliability and circuit routing flexibility.

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