Effect of Ground Guard Fence with Via and Ground Slot on Radiated Emission in Multi-Layer Digital Printed Circuit Board.

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Abstract: In high-speed digital printed circuit board (PCB), the ground guard fence is often used to reduce the radiated emission and the crosstalk. Moreover, it is quite useful for the presence of the ground slot under the signal trace to avoid the reflection and the radiated emission. In this paper, the effects of the guard fence are studied by experimental measurement and numerical electromagnetic simulation. It is found that the ground guard fence acts efficiently as the shielding wall against the signal trace, which results in the significant reduction of the radiated emission. Also, its inherent low radiation property works well at presence of the ground slot under the signal trace.

Introduction

Recently, increased speed and density of high-performance digital circuits and printed circuit boards (PCB) have presented more challenges to circuit and PCB designers due to electromagnetic radiated emission problems. Microstrip line and stripline structures in the high-speed multi-layer PCB are already known well not to be perfect shielded transmission line configuration.[1] Especially, noticeable radiated emission may occur at the microstrip line under the very short switching time of the digital circuits, which becomes one of the primary EMI sources of the PCB. Moreover, when the ground slot is present under the signal trace, large amount of reflection and radiated emission are generated due to the impedance discontinuities of the signal trace. Usually, the ground slot is implemented in the multi-layer PCB, to partition the ground plane and to isolate the ground noises.

In this paper, we have invested, experimentally and numerically, the effect of the ground guard fence and the attached vias for the suppression of the radiated emission from the microstrip line structures. The ground guard fence adjacent to the signal trace with the grounded vias provides the effective grounded wall to the microstrip line structure. The ground guard fence concentrates the field near the signal trace. In the ground guard fence configuration, the grounded vias play a key role, which significantly block the leaky-wave mode propagating through the dielectric substrate, PCB. Together with the grounded vias, the ground guard fence obstructs the surface-wave excitation, which propagates along the top surface of the dielectric substrate. The condensed field propagating through the microstrip line fenced with the ground guard fence with grounded vias reduces the coupling and the radiated emission. So far, the ground guard fence has been studied with respect to the crosstalk noise suppression and the noise isolation, but the effects on the radiated emission has not been studied yet. [2,3] Especially, this study has put more emphasis on the effect of the ground guard fence for the presence of the ground slot.

Measurement & Simulation

Test multi-layer PCB’s were designed with the varied spacing (S) between the signal trace and the ground fence, and with the varied pitch (d) of the via. Also the additional test PCB’s were designed having the slots on the ground plane. For the case of the ground slot, the effect of the ground fence and the grounded via was also evaluated. The radiated emission power was calculated using the method of moment (MoM) simulation for the test structures, while the radiated emission measurement was conducted using a TEM cell (shown in Fig. 2) and an anechoic chamber. The structure of the ground guard fence is illustrated in Figure 1, and the dimensions of the test PCB are listed in Table 1. The simulated and the measured radiation spectrum from the test microstrip line on the PCB are presented in Fig 3 – Fig. 6.
Figure 2 illustrates the experiment setup for the measurement of the radiated power from the microstrip trace on PCB. A TEM cell is employed in this research study. The topside of the PCB is mounted in the TEM cell. Port 2 of a network analyzer is connected to one end of the microstrip line, where the other end of the microstrip line is terminated by 50 ohm. Port 1 of the network analyzer is connected to one of the terminations of the TEM cell. In this configuration, the network analyzer feeds electromagnetic signal to the microstrip line on the test PCB through port 2. The shielding effectiveness of the used TEM-cell is larger than 80dB below 1 GHz. Since the shape of the TEM-cell is like the swelled coaxial transmission line. Since the swelled part of the coaxial line, TEM-cell, is designed and constructed to maintain the original characteristic of coaxial cable, our measurement setup can be considered to be the situation that a radiation source is placed between the inner conductor and the outer conductor of the bulged coaxial line. Therefore, the radiated electromagnetic energy is coupled to the TEM-cell and the coupled signal flows to the ends of the TEM-cell. TEM-cell has two ends, where one is terminated by 50-ohm termination and the other is connected to the port 1 of the network analyzer. A half of the electromagnetic energy radiated from microstrip line structures is appeared on the network analyzer by the form of S12. Although the characteristic of the TEM-cell to measure the radiated power from the radiation source placed in the TEM-cell must be determined, the measured results by this measurement setup makes it possible to relatively compare the radiated emission from the different microstrip structure.

For the numerical electromagnetic simulation of the radiated emission, the radiation loss (RL) was calculated using commercial electromagnetic field solver based on MoM, HP Momentum. Taking scattering matrix from the MoM simulation, the radiation loss is obtained following the equation, $RL = 1 - |S_{11}|^2 - |S_{21}|^2$. Since the PCB is enclosed by the shielded metallic case of the digital system, the radiation pattern is not important parameter for the evaluation of the radiated emission from signal trace on PCB. Therefore, we employed the radiation loss to compare the microstrip line structure in terms of the electromagnetic radiation.

![Figure 2. Experimental Setup for the measurement of radiated emission from the microstrip trace on PCB.](image)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Ws</th>
<th>S</th>
<th>Wg</th>
<th>d</th>
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<tbody>
<tr>
<td>A1</td>
<td>5</td>
<td>5</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>A2</td>
<td>5</td>
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<td>A3</td>
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<td>A4</td>
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</tr>
<tr>
<td>B3</td>
<td>5</td>
<td>5</td>
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<td>100</td>
</tr>
<tr>
<td>B4</td>
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<td>5</td>
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<tr>
<td>D2</td>
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<td>5</td>
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<tr>
<td>D3</td>
<td>5</td>
<td>5</td>
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</tbody>
</table>

Table 1. Design parameters of the test printed circuit board. (unit: mil). For test samples (D1-D3), a 20mil X 150mil slot is designed on the ground plane under the signal trace to measure the effect of the ground slot on the radiated emission. The length of the microstrip line on test PCB is fixed to be 10 cm.

![Figure 3.](image)

(a) The simulated radiation power from the microstrip line on PCB with the ground fence and via, depending on the spacing (S) between the strip line and the guard fence.

(b) Measured radiated emission from the test PCB for sample A1-A4. The radiated emission was measured using a TEM cell and a network analyzer. The lowest one is from A1 (s=5mil) and the highest one is from A4 (s=50mil). The trend of the measured radiated emission agrees well with the calculated result.
Results & Discussion

It is demonstrated that the low-radiation transmission line structure is useful to reduce the radiated emission from the high-speed digital PCB. Its performance was evaluated by using the experimental measurement. Its inherent less leaky propagation property works well at discontinuity on the ground plane such as slot for EMI reduction. The radiated emission was also measure by TEM -Cell and Network Analyzer, as previously presented. The radiation power from signal trace on the PCB placed in shielded structure (TEM-Cell) is proportional to $S/12$ read by the network analyzer, which is presented at Fig. 3, 4, and 6. The spikes and peaks in measured data are caused by the resonance of the TEM-cell.

By observing the measured and the calculated results, the ground guard fence is most effective when it is placed closely to signal trace (small $S$), as shown in Figure 3. Especially, the effect of the design parameter $S$ on the reduction of the radiated emission is significant near 1GHz in both of the numerical and experimental results shown in Fig. 3. The maximum difference between the smallest and the largest radiated emission is larger than 10dB, which means that the A1 radiates nearly one-third of the radiation from the A4. From the experimental and numerical analysis, the ground guard trace is recommended to be close to signal trace (small $S$) to reduce the electromagnetic radiation. The space ($S$) between guard trace and signal trace seems to be important design parameter for ground guard fence. While Fig.3 showed the effect of the design parameter $S$,
Fig. 4 presents the effect of the interval of the grounded via on the radiated emission. For the microstrip line (B's in Table 1) for the numerical MoM simulation and the TEM-cell measurement, the fixed \( W_g, W_s, \) and \( S \) are used. While \( S \) is significant parameter, the interval of the via \( d \) is considered to be not a significant parameter affecting the radiated emission.

From Fig. 5, it is also found that the microstrip line over the ground slot suffers from large amount of the radiated emission problem. While Fig. 5 (a) shows the radiation power from the microstrip line on solid ground plane, Fig. 5 (b) presents the radiation power from the microstrip line on the slotted ground plane. Two microstrip lines used in anechoic chamber measurement shown in Fig. 5 are fed by 130 MHz digital clock driver. At the second harmonic frequency, 260 MHz, the largest radiation happened. At 260 MHz, the difference of the radiated emission between the solid and slotted ground plane microstrip line is more than 22dB. From the measured results, the slot on the ground plane makes the radiation from the microstrip line ten times.

To reduce the radiation in the presence of the slot on the ground plane, we employed the ground guard fence and the grounded via. Measured radiation power shown in Fig. 6 presents the effect of the ground guard fence on the suppression of the radiated emission. As shown in Fig. 6, the ground guard fence without grounded via does not work well for the emission reduction. Over the whole frequency range, the radiated emission is reduced significantly using the ground guard fence with properly grounded vias.

**Conclusion**

We have successfully demonstrated the low-radiation transmission line structure for the high-speed digital PCB and evaluated its performance by using the TEM-cell measurement and the MoM electromagnetic numerical simulation. Its inherent less leaky propagation property works well in the presence of the discontinuity in the ground plane such as slot for the emission reduction.

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