Reduction of Common-mode Radiation by Terminating Guard Trace with Resistors

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Abstract— A microstrip structure with a narrow return plane generates large common-mode radiation. The guard trace attached near the signal line can reduce common-mode radiation. In general, the guard trace needs a lot of via connections to the return plane for keeping the guard trace grounded. The guard trace with long intervals of vias causes resonance and additional radiation. We propose a novel technique for maintaining low radiation by using only two vias at both ends of the guard trace and adding a termination resistor to the guard trace. It was found that the matched termination suppresses guard trace resonance most effectively through a circuit simulation and radiation measurement.

I. INTRODUCTION

Common-mode radiation is a major factor of electromagnetic interference (EMI) from a printed circuit board (PCB) [1]. High-speed signal traces running either above a narrow return plane or close to the edge of a return plane cause common-mode radiation. To suppress EMI below a prescribed level, a scheme for controlling EMI should be deployed at the PCB design stage [2]. For this reason, we have developed the "imbalance difference model" [3], specialized for estimating common-mode radiation quantitatively and quickly.

To reduce common-mode radiation from the PCB, a guard trace running along the signal line is commonly used [4][5]. Placing the guard trace near the signal line enlarges the path of return current and hence reduces the common-mode radiation. The imbalance difference model is able to estimate the reduction effect of the guard trace [6].

Let us consider the application of this technique to the connection with a flexible printed circuit (FPC) as shown in Fig.1. For the fast signal transmission while maintaining signal integrity, the microstrip structure is also required on the two layered FPC because the line impedance should be controlled. Since a signal line near the edge of the return plane is needed for integration, the guard trace is required to reduce common-mode radiation.

II. MECHANISM OF COMMON-MODE RADIATION

A. Simplified Test Board

In general, the guard trace needs a lot of via connections to the return plane with short intervals. The guard trace with long intervals of vias will generate resonances and hence increase the radiation [7]. In a FPC fabrication, via connection needs an additional procedure. For cost reduction, no via connection on FPC is expected.

In this paper, we propose a new technique to eliminate the vias while maintaining low radiation. Eventually, only two vias at both ends of the guard trace are left. Instead, a termination resistor is added at the ends of the guard trace. The termination helps suppress the resonance of guard trace. Figure 1 shows this proposed method where the via at each end of the guard trace is on the PCB, not on the FPC.
In this paper, the termination resistors other than 0 Ω are investigated to reduce the resonance of the guard trace. This is the key point of this paper. The effect of these terminations will be experimentally examined in the next section. In the following, we will discuss the common-mode generation mechanism using the conventional case, no termination resistors on the guard trace (Z_N=Z_F=0 Ω).

B. Imbalance Difference Model and Effect of Guard Trace

The authors have proposed the imbalance difference model to predict common-mode radiation from a PCB. In this model, we focus on the discontinuous point of cross section, for example, point A in Fig 2. We regard this point as a connection of different transmission lines as shown in Fig. 4(a).

First, let us consider the common-mode potential. The potential depends on the degree of imbalance called current division factor (CDF) denoted by h [3]. In the transmission line, V_S and V_R denote the potential of signal and return line, respectively, and V_N denotes the normal-mode voltage, which is equal to V_S–V_R. The common-mode potential V_C is given by

\[ V_C = (1-h) V_R + h V_S = V_R + h V_N. \]  (1)

The CDF is determined from the cross-sectional structure of the transmission line [8]. The CDF takes a value from 0 to 1. For example, a microstrip line with a wide return plane, h is almost 0. The CDF increases with a narrower return plane.

Next, we focus on the connection of the transmission lines. Each part of the transmission lines has a different CDF, h_a or h_b. The common-mode potential of the connected transmission line is shown in Fig. 4(b). The common-mode potential in each section (V_Ca, V_Cb) is not equal. The common-mode potential difference \( \Delta V_C \) is written as,

\[ \Delta V_C = V_{Ca} - V_{Cb} = (h_b - h_a)V_N = \Delta h V_N. \]  (2)

Thus, the two parts are excited by the common-mode potential difference \( \Delta V_C \) on the common-mode model. The common-mode model corresponding to the real structure shown in Fig. 4(a) is depicted in Fig. 4(c). The electromotive

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**TABLE 1 Calculated Current Division Factors.**

<table>
<thead>
<tr>
<th>PCB</th>
<th>Wide part (h_a)</th>
<th>Narrow part (h_b)</th>
<th>( \Delta h ) (h_b–h_a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>0.014</td>
<td>0.137</td>
<td>0.143</td>
</tr>
<tr>
<td>with GT</td>
<td>0.010</td>
<td>0.067</td>
<td>0.057</td>
</tr>
</tbody>
</table>
force $\Delta V_C$ drives the common-mode current on the board, and emits common-mode radiation.

Let us now describe the effect of the guard trace using the imbalance difference model mentioned above. When a guard trace is attached near the signal line, the CDF will decrease because the guard trace acts as an additional return plane. Table 1 shows CDFs for the test board shown in Fig. 2 and the reference board. The return plane of the transmission line between point A and B is narrow, otherwise the return plane is wide. This table shows the decrease of $\Delta h$ with guard trace attached. Eq. (2) shows that the common-mode electromotive force $\Delta V_C$ is proportional to $\Delta h$, and also is the radiation. Then, the reduction of radiation due to a guard trace can be estimated from the ratio of $\Delta h$ of the test board with the guard trace to $\Delta h$ of the reference, 0.057/0.143 = -8.0dB.

C. Guard Trace Resonance and Increase in Radiation

In general, to keep the guard trace voltage to the return plane at almost zero volts, a lot of via connections with short intervals should be placed on the guard trace. When a guard trace with a long via interval resonates, the guard trace voltage will increase at the frequencies of interest.

We focus on the guard trace voltage at point A ($V_{GA}$) shown in Fig. 2. According to the imbalance difference model, $V_{GA}$ can generate another common-mode electromotive force because the guard trace and the return plane are regarded as a transmission line. This can contribute to total common-mode radiation; the same phenomenon occurs at the B point.

In order to suppress the common-mode generation, we must maintain low voltage of the guard trace at both points A and B. The termination resistors on the guard trace shown in Fig. 2, $Z_N$ and $Z_F$, are used for mitigating the resonance. In the next section, we will show the effect of this termination.

III. EXPERIMENT

A. Resonance Mitigation with Guard Trace Termination

In the previous section, it is described that the guard trace voltage at discontinuous points of cross section must stay low. First, these voltages are evaluated with the circuit simulator, 'SPICE'.

The calculation model of a coupled transmission line is shown in Fig. 5. The characteristic impedance of the guard trace is about 65 $\Omega$. We used several termination resistors shown in Table 2, which correspond to the voltage reflection coefficients ($\Gamma$).

![Fig. 5 Transmission-line schematic.](image1)

Table 2 Termination Conditions of Guard Trace.

<table>
<thead>
<tr>
<th>$\Gamma$</th>
<th>-1</th>
<th>-0.9</th>
<th>-0.5</th>
<th>0</th>
<th>0.5</th>
<th>0.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calc. Z ($\Omega$)</td>
<td>0</td>
<td>3.4</td>
<td>21.6</td>
<td>65</td>
<td>195</td>
<td>1230</td>
</tr>
<tr>
<td>Used Z ($\Omega$)</td>
<td>0</td>
<td>3.3</td>
<td>20</td>
<td>68</td>
<td>200</td>
<td>1200</td>
</tr>
</tbody>
</table>

As a result of a detailed calculation, $V_{GA}$ is larger than $V_{NA}$ by around 10 dB, when the common-mode electromotive force ($\Delta V_C$) due to $V_{GA}$ is almost equal to that of $V_{NA}$ [9]. The source voltage $V_0$ in this calculation is 106 dB$\mu$V. The signal voltage $V_{NA}$ is almost 100 dB$\mu$V. Therefore, when the $V_{GA}$ is over 90 dB$\mu$V, common-mode radiation caused by the guard trace voltage will be dominant.

We calculated the voltage on the guard trace under various combinations of $Z_N$ and $Z_F$. Figure 6 shows $V_{GB}$ when only the far-end termination resistor is changed with a short termination at the near end. When $Z_F$ is matched (65$\Omega$), $V_{GB}$ stays at lower than 90 dB$\mu$V almost all over the frequency range. When $Z_F$ is smaller than 65 $\Omega$, $V_{GB}$ increases at the resonant frequencies mentioned in the previous section. When $Z_F$ is larger than 65 $\Omega$, on the other hand, $V_{GB}$ increases at the frequencies corresponding to the resonances of $\lambda/4$, $3\lambda/4$ ... Thus, the resonant voltage increases according to $|\Gamma|$.

Next, we examined the position of the termination resistors, when the termination resistor was matched at 65 $\Omega$. Figure 7 shows that the "both ends" case is the best almost all over the frequency range. However, the "far end" case would be also sufficient. This is an advantage in cost because the number of the resistors should be reduced. Although the "near end" case

![Fig. 6 Guard trace voltage at point B with different termination impedance.](image2)

![Fig. 7 Guard trace voltage at point B with location of termination resistor.](image3)
also mitigates the resonance, $V_{GB}$ is larger than that of "far end" case. This is because the far-end crosstalk is larger than near-end crosstalk. The similar results are observed at point A.

B. Common-Mode Radiation

The radiation from the test board was measured in a semi-anechoic chamber. The board and the receiving antenna were set at 1 m above the floor as shown in Fig. 8. The y axis of the board is vertically directed. The source signal of 100 dB$_{µ}$V was fed through the coaxial cable from a tracking generator of a spectrum analyzer.

The maximum radiation was measured while rotating the test board on a turn table. The results in the case that only the far-end termination is mounted are shown in Fig. 9. The difference of radiation from the reference board that has no guard trace is shown in Fig. 10. The difference means the radiation reduction is due to the guard trace.

Figures 6 and 10 show a good relationship between the guard trace voltage and the radiation. The radiation in the case of matched termination is kept low at almost frequencies of interest. This results from the resonance suppression on the guard trace. It is found that the radiation in the case of unmatched termination increases at the resonant frequencies.

IV. CONCLUSION

In this paper, we proposed a novel technique to eliminate via connection of the guard trace while maintaining low radiation. The guard trace with long intervals of vias makes a resonance on the guard trace, and hence causes further common-mode radiation. Adding a matched resistor at the far end of a guard trace can mitigate the resonance and maintain low radiation.

In future work, we will apply this technique to differential microstrip structures.

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REFERENCES


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