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.**

Key words: electromagnetic interference, printed circuit board, common mode radiation, guard trace, current division factor

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.

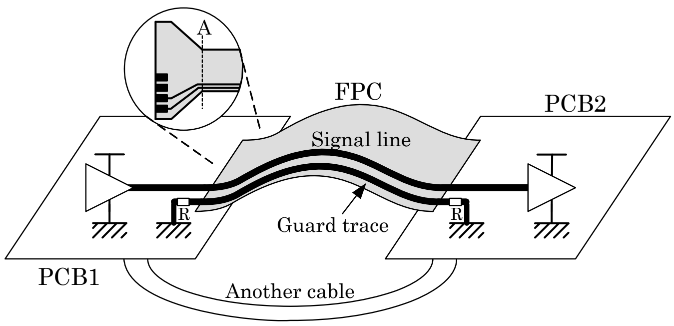

Fig. 1 Two PCBs connected with FPC.

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.

II. Mechanism of Common-Mode Radiation

A. Simplified Test Board

Figure 2 shows a test board that simplifies the system depicted in Fig. 1. In general, there is a tapered region around the end of FPC outside point A in Fig. 1. Section SA in Fig. 2 corresponds to this region and also includes connectors. We used the test board to verify the reduction mechanism to be described in the following. We used a scaled model because of our measurement and fabrication restriction, but the result should also be attainable at a higher frequency range beyond 1 GHz.

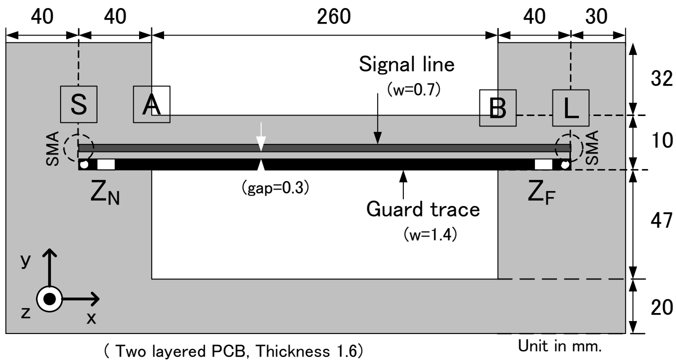

Fig. 2 Test board outline.

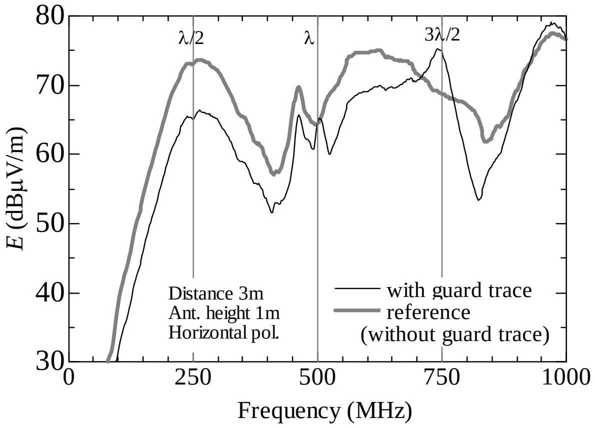

Fig.3 Comparison of radiation between the test board with a guard trace and the reference board.

The test board consists of two layers: the top layer for a signal line and a guard trace; the bottom layer for the return plane. A SMA connector is installed at each end of the signal line from the backside of the board. The characteristic impedance of the signal line is approximately 75 Ω. The guard trace has only two vias at both ends. A termination resistor can be located close to the via and Z_N and Z_F denote near-end and far-end termination impedance, respectively. We also fabricated a test board without a guard trace for the reference.

Figure 3 shows the measured results of radiation from the test board (Z_N=Z_F=0 Ω) and the reference board. The radiation is reduced due to the guard trace but at a few frequencies no reduction or increase of radiation is observed even with the guard trace. These frequencies correspond to the resonance of the guard trace. The test board shown in Fig. 2 has the via interval of 340 mm. A transmission line with short termination at both ends resonates at nλ/2 (n=1, 2...) in length of line, where λ is a wavelength. In this case, the resonant frequencies in consideration of an effective permittivity are multiples of 250 MHz.

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

$$V_C = (1-h)\,V_R + h\,V_S = V_R + h\,V_N. \qquad (1)$$

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 ΔV_C is written as,

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

Thus, the two parts are excited by the common-mode potential difference ΔV_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

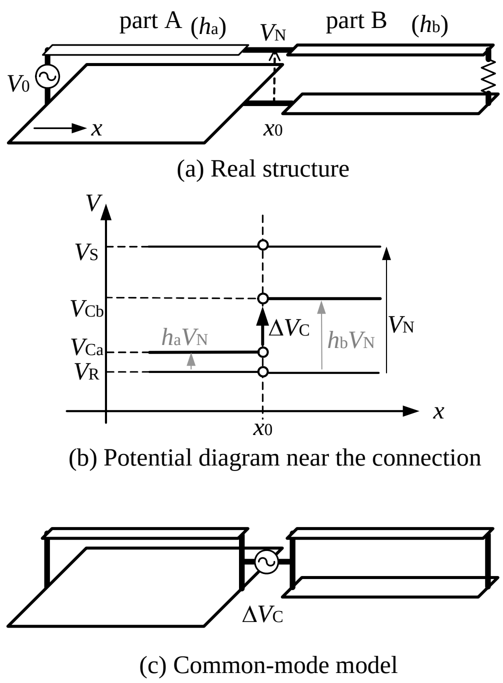

Fig.4 Generation of common-mode source.

TABLE 1 CALCULATED CURRENT DIVISION FACTORS.

PCB	Wide part (h_a)	Narrow part (h_b)	Δh (h_b–h_a)
Reference	0.014	0.157	0.143
with GT	0.010	0.067	0.057

force ΔV_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 Δh with guard trace attached. Eq. (2) shows that the common-mode electromotive force ΔV_C is proportional to Δh, and also is the radiation. Then, the reduction of radiation due to a guard trace can be estimated from the ratio of Δh of the test board with the guard trace to Δh 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 Ω. We used several termination resistors shown in Table 2, which correspond to the voltage reflection coefficients (Γ).

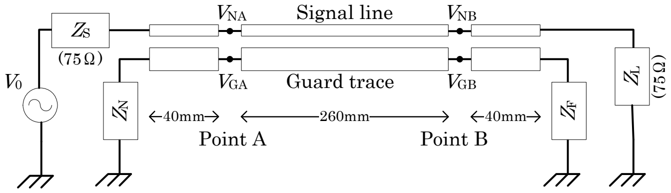

Fig. 5 Transmission-line schematic.

TABLE 2 TERMINATION CONDITIONS OF GUARD TRACE.

Γ	–1	–0.9	–0.5	0	0.5	0.9
Calc. Z (Ω)	0	3.4	21.6	65	195	1230
Used Z (Ω)	0	3.3	20	68	200	1200

As a result of a detailed calculation, V_{GA} is larger than V_{NA} by around 10 dB, when the common-mode electromotive force (ΔV_C) due to V_{GA} is almost equal to that of V_{NA} [9]. The source voltage V_0 in this calculation is 106 dBμV. The signal voltage V_{NA} is almost 100 dBμV. Therefore, when the V_{GA} is over 90 dBμV, 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 (65Ω), V_{GB} stays at lower than 90 dBμV almost all over the frequency range. When Z_F is smaller than 65 Ω, V_{GB} increases at the resonant frequencies mentioned in the previous section. When Z_F is larger than 65 Ω, on the other hand, V_{GB} increases at the frequencies corresponding to the resonances of λ/4, 3λ/4 ... Thus, the resonant voltage increases according to |Γ|.

Next, we examined the position of the termination resistors, when the termination resistor was matched at 65 Ω. 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

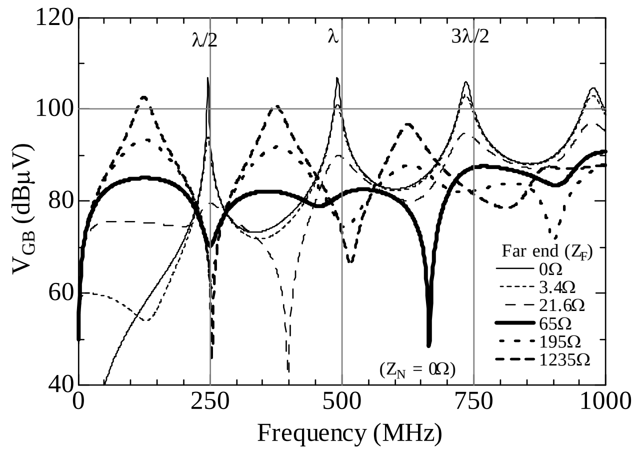

Fig.6 Guard trace voltage at point B with different termination impedance.

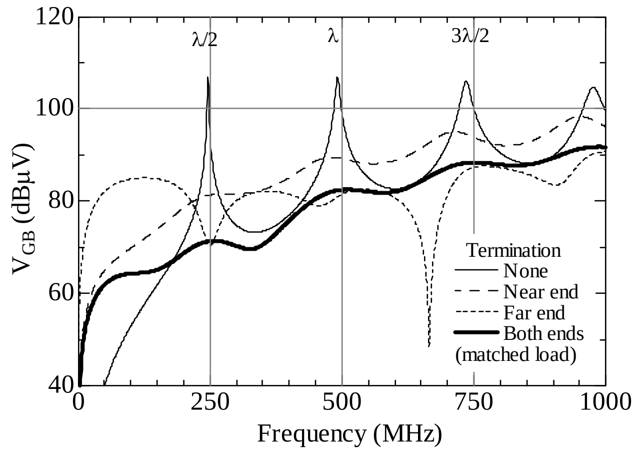

Fig. 7 Guard trace voltage at point B with location of termination resistor.

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 dBμV was fed through the coaxial cable from a tracking generator of a spectrum analyzer.

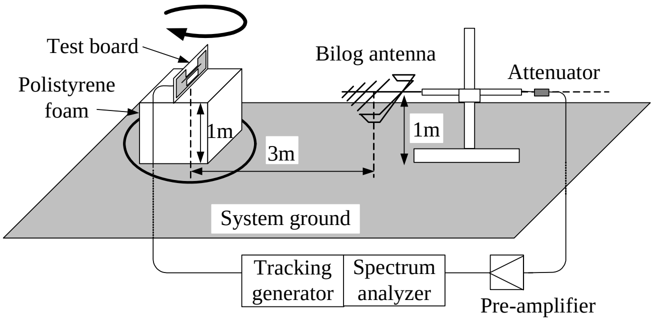

Fig. 8 Measurement setup for radiation.

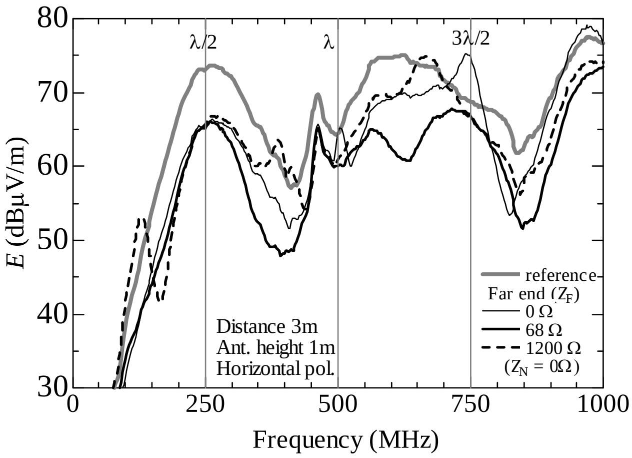

Fig. 9 Comparison of radiated emissions among different termination resistors implemented on guard trace.

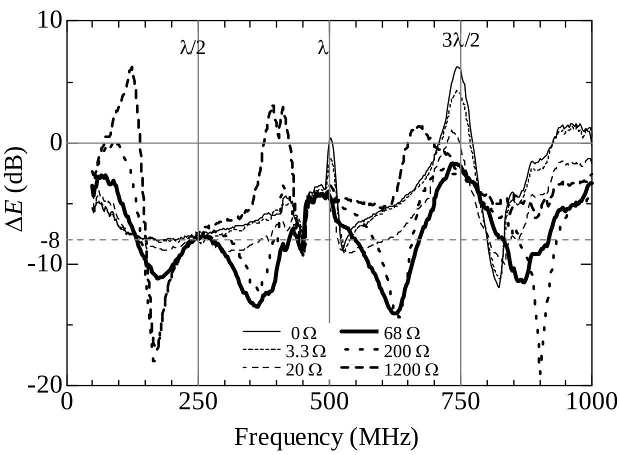

Fig. 10 Comparison of radiation reduction on termination impedance.

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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