# Reduction of Induced Voltages deriving from Ground Return Currents for Two Perpendicular Signal Traces on Printed Circuit Boards

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***Abstract*— Electromagnetic disturbances in vehicle-mounted radios are caused by conducted noise current outflows from vehicle-mounted PCBs (Printed Circuit Boards) to wiring-harnesses. To investigate a design method that can suppress the noise current of this kind, we measured and simulated FM-band induced voltages deriving from ground return currents for spatially different two perpendicular signal traces fabricated on three types of simple three-layer PCBs having the same ground patterns with two slits. The results show that the induced noise voltages can be reduced whenever ground pattern slits are symmetric to one signal trace that equally divides the other trace. This finding was qualitatively explained from a balanced bridge circuit concept.**

**Key words: Vehicle-mounted electronic equipment, three-layer PCB, noise voltage deriving from ground return current, ground layer pattern with slits, balanced bridge circuit.**

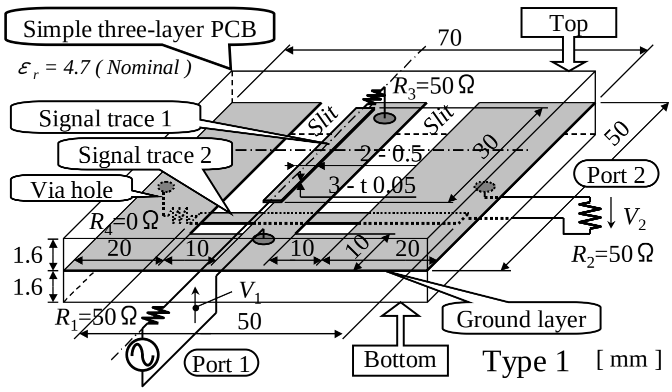
## I. Introduction

It is well known that the conducted noise current outflows from vehicle-mounted printed circuit boards (PCBs) to wiring-harnesses cause electromagnetic disturbances in vehicle-mounted radios [1]-[2]. To reduce the conducted noise current outflows from the PCBs, it is necessary to consider a design method of ground patterns of PCBs that can suppress the noise voltages deriving from ground return currents for signal traces [3]. From this objective, we previously measured the induced voltages for two perpendicular traces on four types of three-layer simple PCBs having different ground patterns with/without slits, and examined the effect of ground patterns on the noise voltages. As a result, we found that the noise levels for the two slits symmetric to one signal trace are smaller compared to the case for the asymmetric two slits ground types [4].

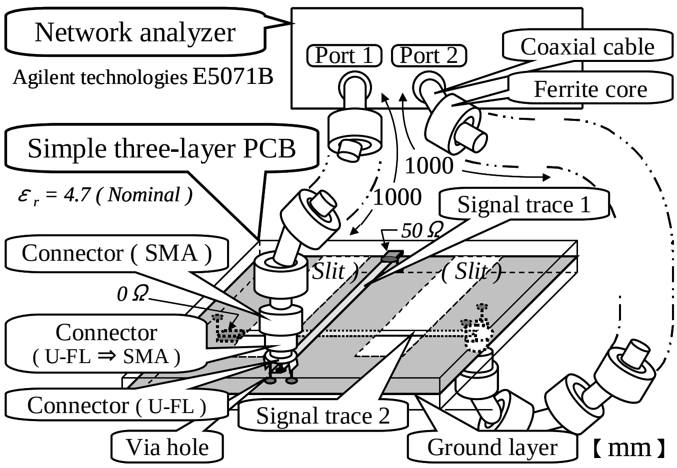
In this study, to further confirm our finding obtained above, with the FDTD (Finite Difference Time Domain) method, we simulate FM-band noise voltages deriving from ground return currents for spatially different two perpendicular signal traces on three types of simple three-layer PCBs having the same ground patterns with two slits, and qualitatively show suppression effects of the noise voltages based on a balanced bridge circuit concept.

## II. Measurement and simulation

Figure 1 (a) shows a type of simple three-layer PCB with two perpendicular signal traces and ground pattern with symmetric two slits for examining the induced noise voltages deriving from ground return currents for two signal traces.



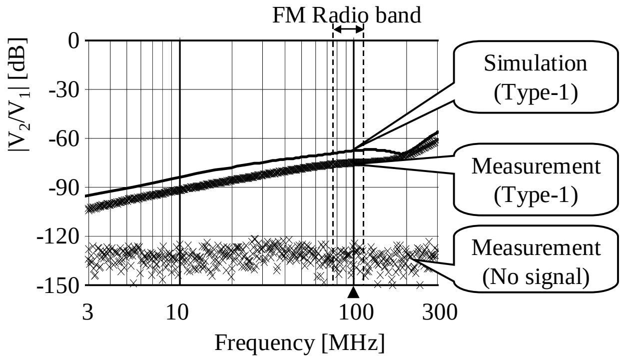

(a) Simple three-layer PCB having two perpendicular signal traces and ground pattern with symmetric two slits.



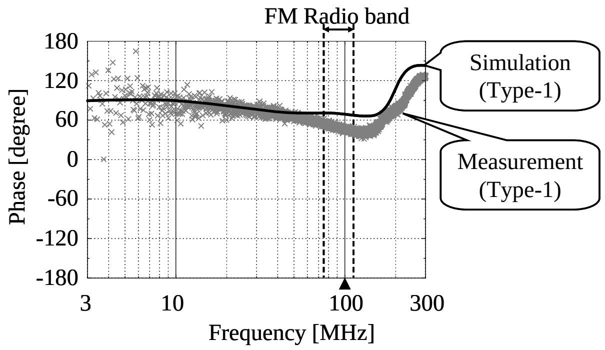

(b) Set-up for measuring induced noise voltages by measuring with a network analyzer.

Fig. 1 (a) Simple three-layer PCB and (b) Set-up for evaluating induced noise voltages deriving from ground return currents for two signal traces.

This PCB is named here type-1, which provides the smallest noise voltage among the other types of PCBs having ground patterns with slits being used in the reference [4]. Figure 1 (b) shows a set-up for evaluating noise voltages via a common ground current for two signal traces by measuring with a network analyzer. With respect to the ground patterns, we evaluated noise voltages appearing at the end of the signal trace 2, which was connected through a 50Ω coaxial cable to Port 2 of the network analyzer, when exciting the end of the signal trace 1 connected to Port 1. The Port 2 and a load resistor $R_3$ (= 50Ω) were assumed to represent the connector section of a piece of vehicle-mounted electronic equipment and the input impedance of a 50Ω coaxial cable connected to a network analyzer, respectively. The resistor $R_4$ (= 0Ω) was assumed to represent a kind of low output impedance of an analogue circuit. We measured reflection and transfer coefficients of $S_{11}$ and $S_{21}$ from the Port 1 to the Port 2 in order to obtain the induced voltage ratio of $V_2/V_1=S_{21}/(1+S_{11})$ (see in Fig.1(a)). In this case, due to the finite ground plane and mismatching reflection at the points connected between the inner conductors of the coaxial cables and the traces, some currents should flow on the outer conductors of the coaxial cables, which may give measurement errors for $S_{11}$ and $S_{21}$. In order to reduce the above undesirable currents, ferrite cores were used on the coaxial cables as shown in Fig. 1 (b).




(a) Frequency characteristics of amplitude of $V_2/V_1$.

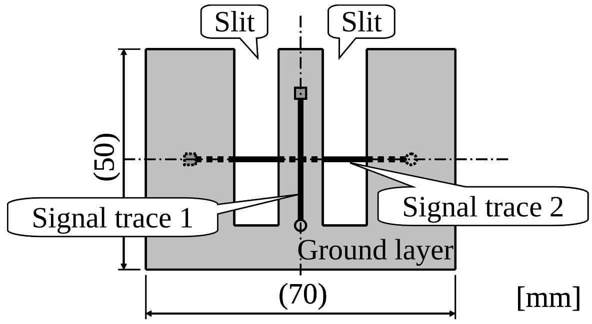



(b) Frequency characteristics of phase of $V_2/V_1$.

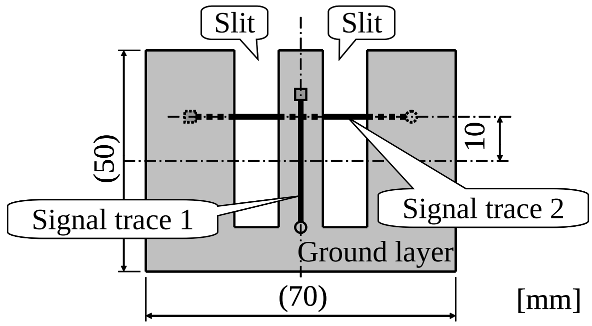
Fig. 2 Measurement and simulation of frequency characteristics of $V_2/V_1$.

Following the measurement, we simulated the induced voltage ratio $V_2/V_1$ with the FDTD method. Detailed description of simulation can be found in Ref. [5].

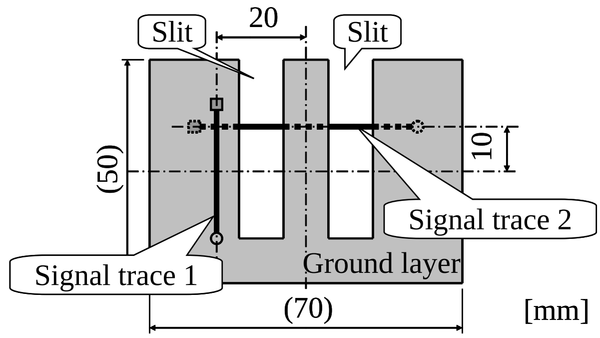
Figures 2(a) and 2(b) show the measured and simulated frequency characteristics of amplitude and phase, respectively, for the induced voltage ratio $V_2/V_1$, which demonstrate that there is fair agreement between the measurement and simulation for the type-1, though the simulated levels are somewhat larger than the measured ones. The reason for the latter is not clear at present, while it may be due to the measurement errors caused by the currents flowing on the outer conductors of the coaxial cables.




(a) Type-1




(b) Type-2




(c) Type-3

Fig. 3 PCBs having different allocation of two perpendicular signal traces (on the top view).

### III. Dependence on signal-trace allocation of noise voltages

#### *A. Three models of simple three-layer PCBs*

Figure 3 shows three types of simple three-layer PCBs having different allocation of two perpendicular signal traces and identical ground patterns with two slits, which were used for examining the trace allocation effect of induced noise voltages deriving from ground return currents for two signal traces. The type-1 PCB has two perpendicular signal traces divided each other into two equal parts, as shown in Fig. 3(a) and is the same as the model that was described in the preceding chapter.

The type-2 PCB has signal trace 1 symmetric to two slits as well as the type-1, which is perpendicularly divided signal trace 2 into two equal parts as shown in Fig. 3(b). The type-3 PCB has two perpendicular signal traces asymmetric to two slits, which are not divided each other into two equal parts as shown in Fig. 3(c).

We simulated the induced noise voltages for the above three types of PCBs with the FDTD method.

#### *B. Results and Discussion*

Figure 4 shows the simulated results, which demonstrates that the simulation for the type-2 is a bit larger than the one for the type-1, while it is smaller by 25-28dB at 100MHz than the case for the type 3. Also shown in Fig. 4 are the dents observed around 190-200MHz not in type-3 but in type-1 and type-2. The reason is not clear at present, which should be investigated in the future subject.

In order to understand the above finding, we paid attention to ground return currents via common ground pattern for two signal traces [6]. We qualitatively explain the effect on allocation of two signal traces of the induced noise voltages from a bridge circuit concept we previously proposed [4], which was based on a lumped parameter approach.

Figure 5(a) shows an equivalent bridge-circuit of the simple PCB shown in Fig. 1(a), which can be used for two perpendicular traces despite any flow distribution of ground return currents. In that case, signal traces and ground paths along which their return currents flow were replaced with inductances. The capacitances between the traces and ground, and crossing capacitance of the traces were ignored under the assumption that their reactance may be sufficiently large compared to the one of the inductances in the frequency range for the FM band. The equivalent circuit of this kind consists of the inductances: $L_i$ (i=1,2) of the signal trace i and $l_{ij}$ (i=2,3,4; j=1,2,4) between Node i and Node j of the ground layer pattern. Also shown in Fig. 5(b) is the one rewritten for a better understanding of the dependence of $V_2/V_1$ on the circuit parameters shown in Fig. 5(a). Since the inductances $l_{ij}$ change according to the flow distribution of ground return currents, these inductance values are difficult to calculate from their geometrical dimensions. When the Port 1 is excited to apply $V_1$, in order to suppress an output voltage $V_2$ appearing in the Port 2, the electric potentials at points A and B should be identical, or more return currents should bypass via the path $l_{31}$ from Node 3 to Node 1 or the pass $l_{24}$ from Node 4 to Node 2. Form the above idea, it follows that the circuit inductances need to be satisfied at least with one of the following conditions:

(1) $\omega l_{21} \times \omega l_{34} = \omega l_{41} \times \omega l_{32}$,
(2) $\omega l_{31} << \omega L_1$,
(3) $\omega l_{24} << \omega L_2$,

where $\omega$ is the angular frequency. The condition (1) makes the bridge circuit balance so that no currents flow on the signal trace 2, which means that no cross-talks appear. The conditions (2) and (3) make the return currents bypass the ground, which results in reducing the noise voltages on the signal trace 2. Since the signal trace 2 is divided into two equal parts by the signal trace 1, the type-1 and type-2, which

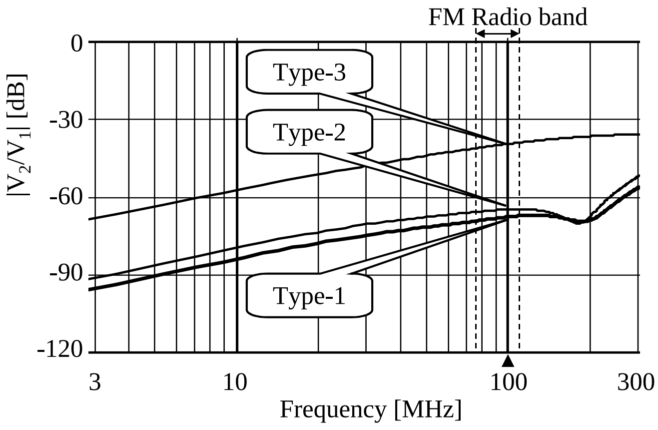
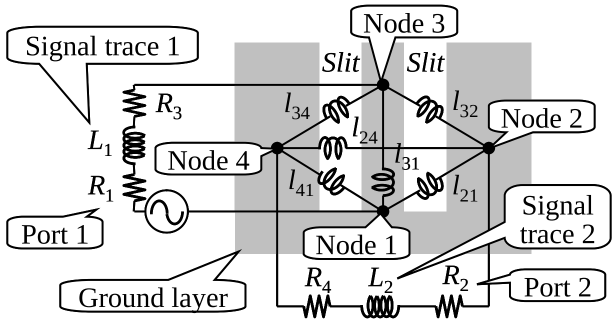
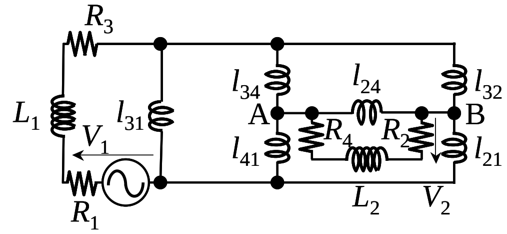



Fig. 4 Simulation results of frequency characteristics of $|V_2/V_1|$ for three-types of PCBs.




(a) Equivalent bridge circuit for three-layer PCB shown in Fig. 1(a).




(b) Equivalent bridge circuit rewritten for a better understanding of suppression effects of $|V_2/V_1|$.

Fig. 5 Equivalent bridge circuit of simple three-layer PCB based on return circuits of common ground pattern (example for Type-1 PCB).

have ground pattern with two slits symmetric to the signal trace 1, almost satisfy the condition (1), while the type 3 does not satisfy the condition (1). Accordingly, the induced noise voltages of the type-1 and the type-2 are significantly smaller compared to that of the type 3, though the noise voltage of the type-1 is slightly smaller than that of the type-2. This may be because the $\omega l_{24}$ of the type-1 is smaller compared to that of the type-2 due to the shorter return path, which results in that more return currents for the type-1 bypass the ground than the case for the type-2.

## IV. CONCLUSION

In order to investigate the induced noise voltages deriving from ground return currents for two perpendicular signal traces on PCBs, we measured and simulated the noise voltages for three types of simple three-layer PCBs that have different two perpendicular signal traces and the same ground layer patterns with two slits. As a result, we found that the noise voltages at 100 MHz can be reduced by 25-28dB whenever ground pattern slits are symmetric to one signal trace that equally divides the other trace, which was qualitatively explained from an equivalent bridge circuit model we previously proposed.

The future work is to find out a quantitative measure of ground-pattern designing that can be used in actual PCBs.

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