ON EFFECTS OF SLOT IN PCB GROUND PLANE INTERCONNECTION

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Abstract: In case of PCB interconnection, slots in a ground plane make a far-field emission increase and signal integrity worsen. Therefore, it is required to investigate the mechanism of the emission and the signal transmission, and to give a guide for low-emission and highly signal-integrity designing. In this paper, we show experimental results of near electromagnetic-field distributions, far-field patterns, and reflection/transmission waveforms. Then we discuss on the results on the viewpoint of emission and signal integrity.

Key words: Signal integrity, Near-field distribution measurement, Far-field pattern

1 Introduction

Because of the improvement of clock frequency in electronics equipment, it is required to reduce a far-field emission and to transmit signals without distortion. Besides, demand of high-density packaging reduces a margin for trace patterns on printed circuit board (PCB). Especially, in case of PCB interconnection, trace patterns sometimes should cross over a slot in a ground plane or a gap between two ground planes. Such configuration has a high potential to increase the emission and to worsen the signal integrity.

In this paper, we discuss on the experimental results of near electromagnetic-field distributions, far-field radiation patterns, and reflection/transmission waveforms for various slot models.

2 PCB model

Figure 1 shows PCB models, which were of glass-epoxy material (FR4) of permittivity of 4.7 and thickness of 1.6 mm. The width of pattern trace was of 3 mm, therefore the characteristics impedance was about 50 Ω. The width of slot was of 1 mm, which was in orthogonal directions to the pattern trace. SMA connectors were attached to the ends of the trace with via. Figure 2 shows the models considered here; model (a) denotes the original and model (b) is for the transmission-line system crossing over the ground plane perfectly separated with a slot. Models (c) to (f) were for the systems having a slot beneath the trace, and modes (g), (i), and (j) for the ones having no slot beneath the trace, and model (h) for one having a slot beneath the trace but neighboring the ground-connection point. In models (d), (e), and (g), the slot run to the one end of the ground plane, and, in models (h), (i), and (j), the two slots in the same direction run to both ends.

3 Near-field measurement

One terminal of the strip line was terminated with 50-Ω load and other terminal was excited by a network analyzer. A probe for measuring magnetic fields $H_x$, $H_y$, and electric field $E_z$ [1] scanned above 10 mm from the PCB and obtained near electro-magnetic fields of both magnitudes and phases. Figures 4 to 13 shows the obtained fields at 1050 MHz.

3.1 $H_x$ components

The $x$ component of magnetic field $H_x$, which was in the direction of the strip line, was generated by the current of the direction orthogonal to the strip line and normal of the ground plane.

The model (a), which had no slot, had two null lines. Because the distance between these lines was half wavelength on the PCB of 1050 MHz, it is thought that this was caused by the standing wave due to currents of both risers [2]. The models with a slot had null amplitude of $H_x$ on the slot and opposite phases on both sides of the slot.

Although model (g) had no slot beneath the strip line, the slots acts as slot line. It is thought that this is caused by slot excitation due to the electromagnetic
field caused by the strip line.

3.2 $H_y$ components
The $y$ component of magnetic field, which is in the orthogonal direction to the strip line, is generated by the current of the direction to strip line and the normal of the ground plane. The models (c), (d), and (h) had strong $H_y$ at the region of interconnection. This was caused by the concentration of the return current.

3.3 $E_z$ components
The $z$ component of electric field, which is the normal direction of the ground plane, is generated by potential between strip line and ground plane. The models with slot had null amplitude of $E_z$ on the slot and opposite phases on both sides of the slot. From this fact and the result of $H_x$, we found that the slot acts as a slot line.

4 Far-field pattern measurement
We measured far-field patterns in a full-anechoic chamber. One terminal of the strip line was excited by a network analyzer and other terminal was terminated with a 50-Ω load. PCB was placed to a ground plane lied on the horizontal plane. Figure 14 shows results.

4.1 Horizontal patterns
We discuss about horizontal patterns. The horizontal component of far field is generated by the strip line and the slot line. Models (d), (e), (g), and (h), which have an asymmetric slot, have asymmetric far-field patterns and larger emissions in the direction of the slot. Although model (g) had no slot beneath the strip line, emission in the direction of slot was increased. It is thought that this was caused by excitation of the slot due to the electromagnetic field caused by the strip line. Results of near-field distribution measurement agreed with this fact.

4.2 Vertical patterns
We discuss about vertical patterns. Vertical component of far field is generated by risers of the transmission line. Far-field patterns of models (b), (c), (f), (i), and (j), which were symmetry model, were asymmetry though the far-field pattern of model (a), which had no slot, was symmetry. To investigate this reason is a further problem.

5 Time-domain measurement for reflected/transmitted waveforms
One terminal of the strip line was excited by a step pulse with rise time 45 ps, repeat late 20 ms, amplitude 200 mV. A digitizing oscilloscope with band width 20 GHz, equivalent sampling interval 1.22 ps acquired the waveforms at both terminals. Figures 15 and 16 show reflected and transmitted waveforms obtained here.
At time a in Figs. 15 and 16, models with slot beneath the strip line had no variation on the waveforms, though models without slot beneath the strip line had variation on the waveforms. It is thought that this was caused by discontinuity on the strip line crossing the slot. At time b, models (e), (f), and (h) showed the minimum of reflected waveforms and the maximum of transmitted waveforms. Because they had a slot of 1-cm length, it is thought that the step pulse was branched to the slot line and reflected at the end of the slot line. Time c is similar to this case for model (b) and (c) with 4 cm slot. At time d, the waveforms of models (b), (c), (d), (e), and (h) were of maximum. Because these models had a penetrated slot of 5-cm length, it is thought that they were due to the reflection from the end of the slot line. Those changes of waveform at times a, b, c, and d will give a knowledge of terminal conditions of the slot line.

The models (a), (g), and (i), which had no slot beneath the strip line, had the same transmitted and reflected waveform. From this fact, it is said that the slot does not affect the signal integrity as far as a PCB is grounded beneath the strip line.

6 Conclusion

We have investigated near-field distributions, far-field patterns, and reflected/ transmitted waveforms regarding the shape of a slot in a ground plane. Qualitative knowledge about the effects of slot for emission and signal integrity were obtained. We found that we should study from the viewpoint of both signal integrity and emission since some model has bad signal integrity and good emission (model b) while other model has good signal integrity and bad emission (model e).

Based on the obtained knowledge, our future work is to obtain analytical expressions of signal integrity and emission for strip line with slot in the ground plane.

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References


Figure 11. Measured near fields for model (h)

Figure 12. Measured near fields for model (i)

Figure 13. Measured near fields for model (j)

Figure 14. Measured far-field patterns

Figure 15. Time-domain reflected waveforms

Figure 16. Time-domain transmitted waveforms