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ESD field coupling study in relation with PCB GND and metal chassis

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***Abstract*—This work demonstrates a simple experimental setup to measure ESD-induced voltage to traces on a printed circuit board when ESD current is injected directly onto the outside of a metal case and presents how the induced voltage can be affected by the physical structure of the PCB ground and the metal case.**

The correlation between ESD-induced voltage and the method of connecting the PCB and chassis grounds shall be discussed, as well as how the PCB ground fill affects ESD. These experimental results may provide guidance for a better design for ESD immunity.

I. Introduction

The tight noise margin for the low voltage in high speed digital circuits and physically high density and small product-trend challenge engineers to pass the ESD standard test in IEC61000-4-2[1]. One of reasons that analysing ESD failure and solving ESD problems seem difficult is that there are many cases which cause ESD failure in system level. For example, ESD current is directly injected into signal traces, which destroys ICs (called hard-error), ESD transient field is electrically or magnetically coupled to traces, or direct field coupling to ICs occurs as well. These incidents often occur all together when ESD is injected into electronic devices. In this paper, expected soft-error problem by coupling metal chassis and traces on PCB is discussed, ESD current being injected to outside of the product.

Once ESD is discharged to the outside of a system, the ESD current is distributed in the system. It is associated with a strong electromagnetic field that can couple into the enclosure through apertures, cables, and slots. There it induces voltages and currents. These voltages or currents may cause bit-errors, wrong instructions, or even a system crash [2]. There is limit to solving ESD failure problems resulting out of the foregoing causes mentioned earlier with artwork design or ESD protection devices. Therefore, to improve ESD immunity of digital devices, understanding of the affect of connecting chassis to PCB ground and applying PCB ground fill is necessary.

The experimental setup to measure induced voltage used in this paper is described in Part II. The effect of PCB ground fill and chassis connection is presented in Parts III and IV.

II. DUT and Experiment Setup

The DUT (device under test) is shown in Figure 1. A 3 cm by 3 cm square loop-like trace was placed on top layer and the both ends of the trace are connected to probing pads on bottom layer through vias.

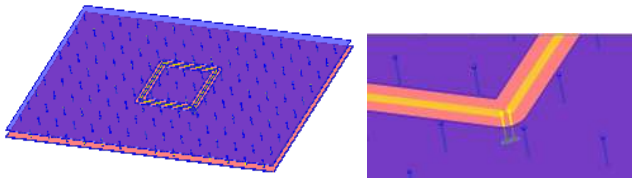


Fig. 1. Loop structure to measure induced loop voltage (left) and magnified view of via and probing pads (right).

The loop is finally connected to coaxial cable containing ferrites. The other end of the coax is connected the oscilloscope. A 40 dB attenuator is placed in the middle of the coaxial cable to prevent damaging the oscilloscope. As a chassis, a solid copper plane is placed a bit length away from PCB. Distance between the PCB and copper plane can be controlled by the length of 8 screws. In this experiment the distance between the PCB and copper plane is fixed to 8 mm. One via connects to the oscilloscope and the other is terminated by 50-Ohm. The bottom of the PCB and the ground strap are connected to a standard ground table. The experimental setup is shown in Figure 2.

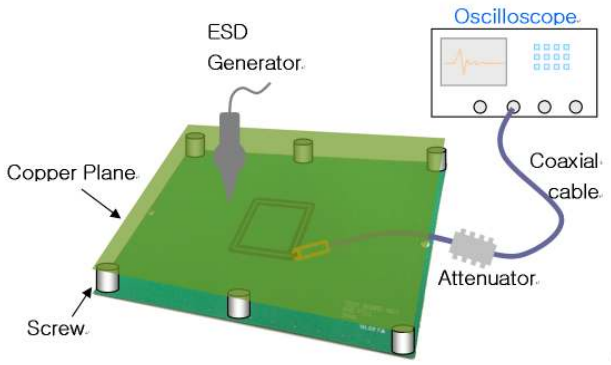


Fig. 2. Experimental setup for induced voltage measurement

An ESD generator (EM test) in contact mode is set to 1 kV, 2 kV, 3 kV and discharges to the midst of the upper copper plane. Figure 3 shows the induced voltage waveform measured by the oscilloscope.

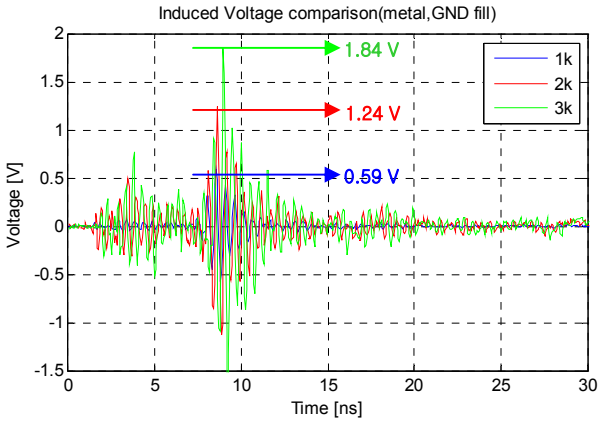
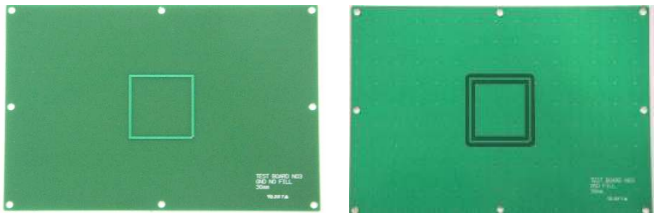


Fig. 3. Induced voltage measured by Oscilloscope with an ESD generator charged up to 1kV, 2kV, 3kV

The measurement setting is quite fine in that the measured voltage is almost linear in contact mode and the signal rises as fast as expected. The noise occurring at the first 7-8 ns may be partially caused be the cable to the oscilloscope.

III. Ground Filling

Ground fills are generally used on top and bottom layers of a PCB to prevent EMI radiation. From an ESD point of view, an EMC engineer might assume that ground fill has a good effect. In other words, a ground fill makes digital devices more robust in ESD immunity. To prove this assumption is correct, PCBs with and without GND fills are designed and the results are compared. The board (a) only has bottom ground but (b) has top ground and well connected to bottom ground by a hundred of vias. The spacing between the ground fill and the trace is 2 cm.



(a) (b)

Fig. 4. Top view of test boards (a) 2-layer PCB without GND fill. (b) 2-layer PCB with GND

The induced voltage is measured and the results are shown in Figure 5. The ESD generator is set to 1 kV, and the PCB and top metal chassis are connected by metal screws.

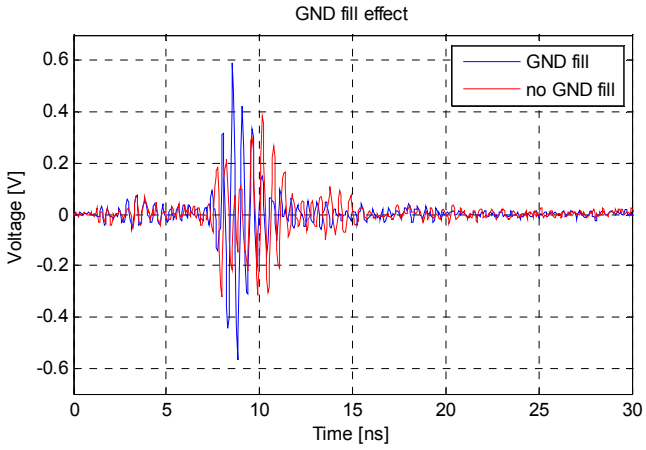


Fig. 5. Measured induced voltage on trace with GND fill PCB and without GND fill PCB(The PCB ground and the top copper plane are connected).

Based on this measurement result, a GND fill does not reduce ESD transient field coupling from metal chassis. On the other hand, a GND fill slightly increases field coupling. This phenomenon occurs with different voltage setting of the ESD generator. From this result, it could be deduced that magnetic field is coupled by GND right next to the trace as well. This deduction must be proven by case study later.

For the case when the PCB and metal chassis are not electrically connected, a GND fill has little effect on ESD noise coupling. The result is shown in Figure 6.

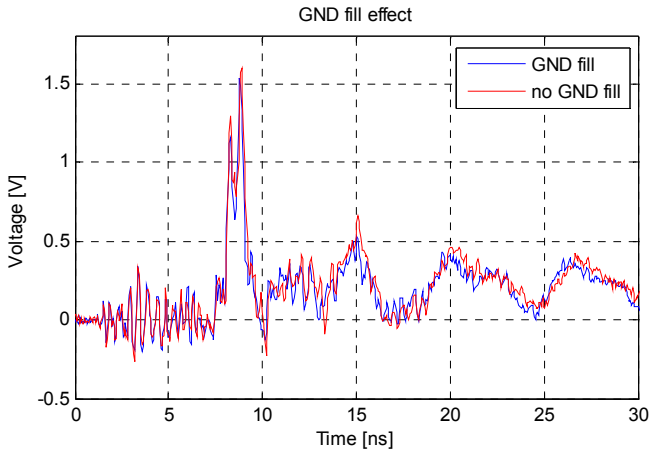


Fig. 6. Measured induced voltage on trace with GND fill PCB and without GND fill PCB(The PCB ground and the top metal chassis are not connected).

IV. PCB & Metal-case Connection

It is common sense for EMC engineers that connecting metal chassis with PCB ground is a design guideline to reduce EMI radiation level by the shielding effect. However, it might be a different story in ESD point of view. It's convinced that electrically separating PCB from metal chassis can be guard structure, that leads the injected current not to break into PCB, assuming that there is no spark occurring. In spite of no injected current flowing into PCB, noise is induced by the fields radiated from the ESD generator or by rapid current

spreading. This experiment demonstrates how field noise coupling is influenced by separating the PCB ground and metal chassis. Plastic screws are used to electrically separate the PCB and metal chassis as shown in Figure 7.

(a) (b)

Fig. 7. Screw between metal chassis and PCB ground. (a) Metal screw. (b) Plastic screw.

The measurement process is the same as in the GND fill effect test and the results are shown in Figure 8. The ESD generator was set to 1 kV.

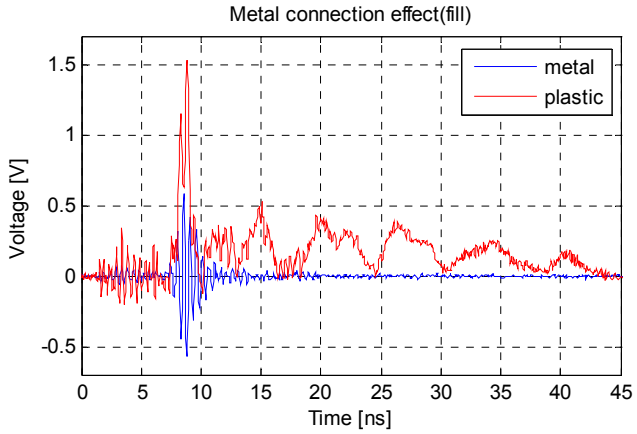


Fig. 8. Comparison waveform of measured induced voltage on trace, placing metal screws and plastic screws

Comparing these two waveforms, the induced voltage level is reduced when the top metal chassis and PCB ground a re connected. The moment the ESD pulse is discharged onto the top metal chassis, the PCB ground and the chassis have the same electric potential, which prevents the electric field from coupling to the trace.

Separating the PCB ground and metal chassis has little effect on ESD field noise reduction, since both the electric and magnetic field are dominant in noise coupling.

V. Verification with Full Wave Simulation

To simulate the coupling into the traces for frequencies up to 3 GHz, a full wave numerical model of an ESD generator is required. A variety of full wave models from different EDA companies have been published for ESD prediction. In this paper an improved model from CST Microstripes is used, which has been recently designed in the article [3]. The full wave model of the ESD generator (Dito, EM test) and the test vehicle is shown in Figure 9.

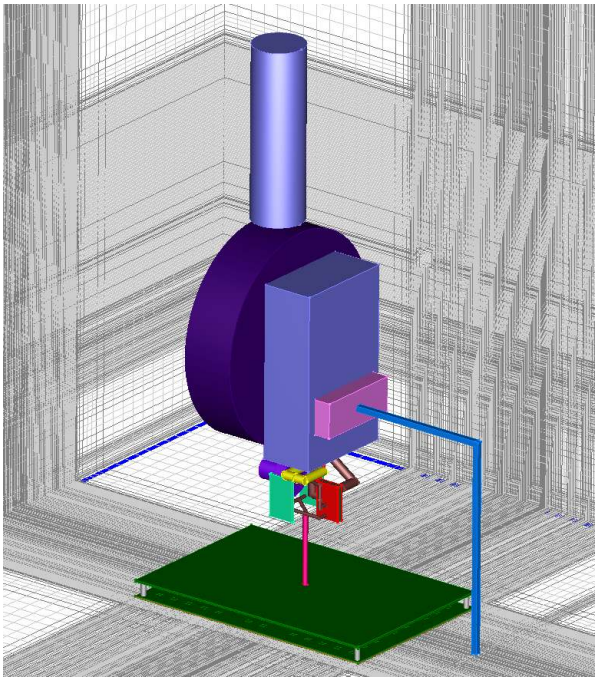


Fig. 9. Full wave model of the ESD generator and the test vehicle (CST Microstripes)

This model contains approximately 250,000 meshes, runs up to 3 GHz, and takes approximately one hour for a PC with a 64-bit dual core CPU to complete the simulation. The simulated results of the GND fill effect are shown in Figure 10.

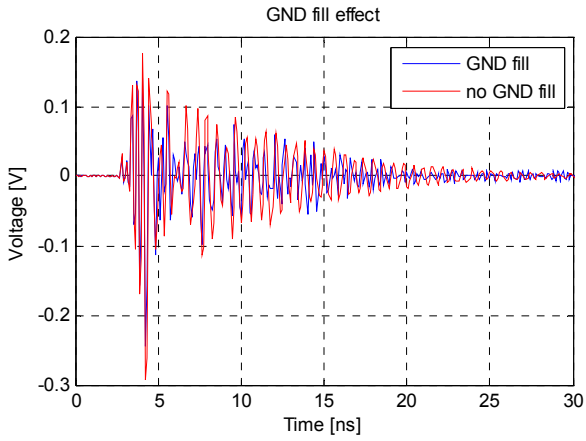


Fig. 10. Simulated result of ground fill effect when top metal plane and PCB ground are electrically connected.

Unlike the measurement, the simulated result shows that the GND fill slightly reduces ESD transient field coupling from metal chassis. This discrepancy may come from either difference between measurement and simulation setting or measurement error. However, as the top metal plane and PCB ground are separated, the simulated result is consistent with the measurement. That is, the GND fill has little effect on ESD noise coupling. This is shown in Figure 11.

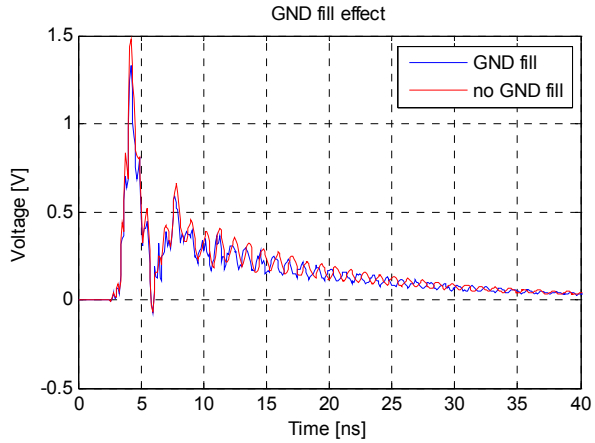


Fig. 11. Simulated result of ground fill effect when top metal plane and PCB ground are electrically separated.

VI. Measurement vs Simulation

In this section, waveforms from measurement and simulation are compared to analyze the validity of the full-wave model. For separating top chassis from PCB GND case, it has really good agreement in that both results have almost same level of peak voltage (see Figure 12). As connected, the measured result has higher peak-to-peak level than the simulated result (see Figure 13).

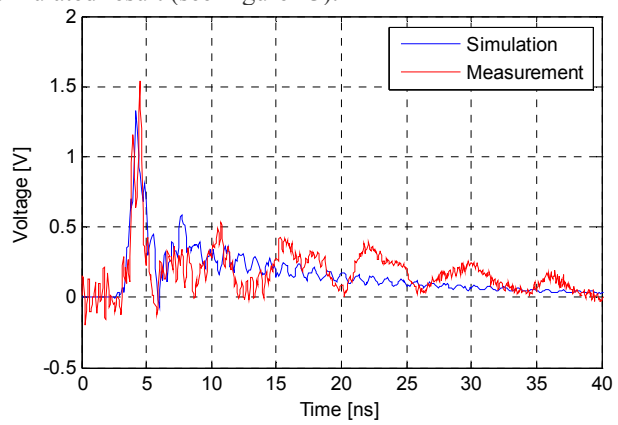


Fig. 12. Comparison of Measurement vs Simulation when top chassis and PCB GND are separated.

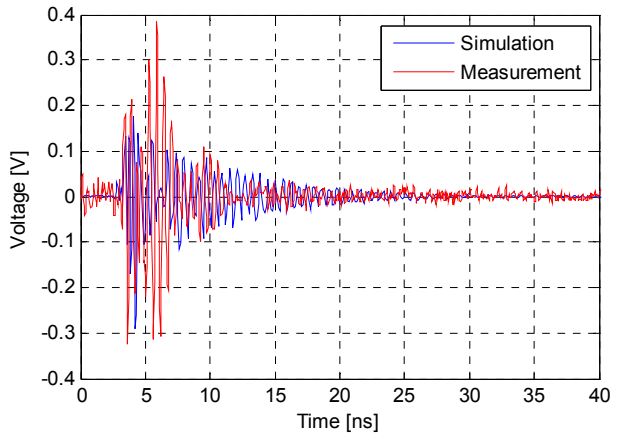


Fig. 13. Comparison of Measurement vs. Simulation when top chassis and PCB GND are connected..

VII. Conclusion

This experiment could be used to measure ESD-induced voltage to traces on a printed circuit board when ESD current is injected directly to outside of metal chassis in several ways. So far, the effect of separating the PCB from the metal chassis and GND fill has been analyzed by measurement data and they are compared by peak value in the time domain. From the data, it can be recommended for EMC designers to electrically well connect the PCB ground and metal chassis, from the perspective of ESD immunity, since this metal connection minimizes E-field coupling to trace when ESD occurs. GND filling does not have a significant effect on ESD immunity. How well it works depends on how close ground filling is placed from traces. This subject is to be studied in detail.

The measured and simulated results are not perfectly consistent, however it would be a challenge to improve the full-wave model and to have exactly the same settings as the measurement. Theoretical basis and better agreement between simulated and measured results are to be studied further.

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