FDTD SIMULATION OF CURRENT BEHAVIOR IN A TRANSMISSION LINE EXCITED BY AN ESD GUN

Xiaojiang ZHANG†, Osamu FUJIWARA†, Yukio YAMANAKA††
†Nagoya Institute of Technology
††Independent Administrative Institutions, Communications Research Laboratory
Gokiso-cho, Showa-ku, Nagoya 466-8555, Japan
E-mail: fujiwara@odin.elcom.nitech.ac.jp

1. Introduction

It is well known that electrostatic discharge (ESD) can cause malfunction or destruction of digital electronic equipment. The ESD immunity test, being known as IEC 61000-4-2 [1] is becoming an essential task for providing an electronic product into the market. In IEC 61000-4-2, a detailed waveform of the discharge current injected by an ESD-gun is prescribed, and its calibration is required by injecting the discharge current directly onto the specially designed target, so-called “Pellegrini target”. However, there is not a guarantee that the IEC prescribed current is indeed injected into an actual device. This is mainly because the discharge current can be affected generally by the device itself. Without an accurate understanding for the discharge current, an ESD countermeasure may do not work. Since the ESD countermeasure should be made in the early design stage of electronic products, computer simulations play an important role in this stage. It is helpful to understand the basic mechanism of ESD phenomena and is effective to derive design guidelines in order to reduce ESD damages.

In this paper, a finite-difference time-domain (FDTD) modeling for the contact discharge with an ESD-gun is proposed. Its validity is shown by applying it to a transmission line structure.

2. FDTD Modeling

An ESD gun is generally designed to realize the discharge current waveform specified in IEC61000-4-2. The current waveform is based on measurement of actual human-body discharge. Figure 1 shows the configuration of an ESD-gun and its FDTD model. It consists of a capacitor of 150 pF and a series resistor of 330 Ω, which correspond to the capacitance and skin resistance of the human-body, respectively. For the junction part in Figure 1(a), although its internal structure is unclear, it should be a rational assumption that the junction part acts as a switch for charging the capacitor from the power source and discharging it to the tip electrode. By injecting a discharge current through the ESD-gun, the electromagnetic (EM) immunity of electronic devices is tested.

In the FDTD modeling, the ESD-gun was simulated with 1-mm cubes and the corresponding electric properties were assigned to the cells. As shown in Figures 1(b) and 1(c), the resistor R was simulated as a dielectric cylinder with its actual dimensions (conductivity $\sigma = l/(R \cdot S)$; l: length, S: cross-section area). The switch was simulated as a lumped inductor L. The condenser unit was replaced with a metal object (σ=3.6×10^7 S/m) with the same shape. The charge and discharge were performed by applying adequate voltage sources across the gap between the metal object and the resistor, respectively. In the charge process, the switch was open, and the voltage source was given by

$$v(t) = V_c(1 - e^{-t/\tau})$$

where V_c is a charge voltage, τ is a time constant of charge, and the charge time was chosen as 5τ. In the discharge process, however, the switch was replaced by the inductance L, and the capacitor C was simulated as an internal lumped component of the voltage source, which was given by

$$v(t) = V_c(1 - e^{-t/\tau}) - \frac{1}{c}\int_{\tau}^{t} i_s(t)dt$$

where $i_s(t)$ is the current flowing from the metal object to the resistor.

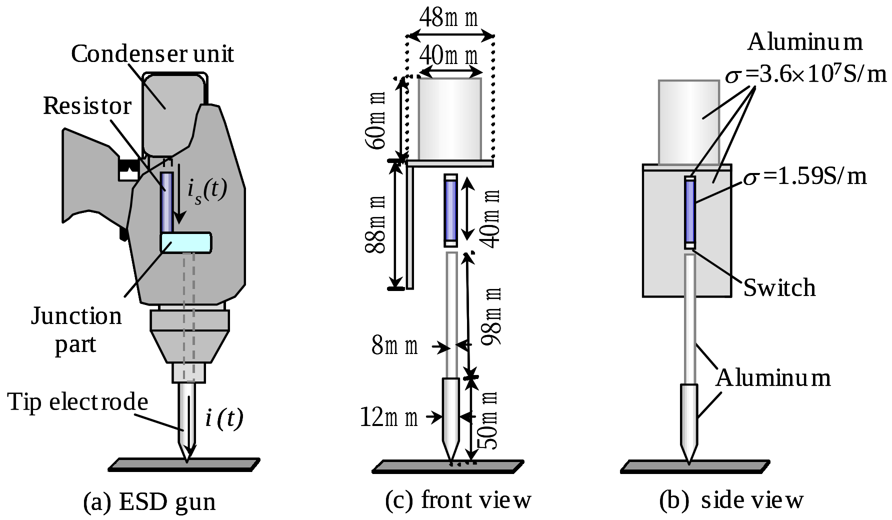

Figure 1 The FDTD model of an ESD-gun.

3. Validation

In order to validate the FDTD modeling described above, we compare the simulated and measured current waveforms flowing on a transmission line excited by an ESD-gun. The ESD-gun injected a current onto a transmission line on a metal ground plane. Its earth return line had a length of 50 cm and was connected to the ground plane. The transmission line had a height of 4 mm from the ground plane and a length of 150 mm. The both ends of the transmission line were terminated with a lumped resistor of 50 Ω, In the FDTD calculation, the structure was simulated with 1-mm cubic cells. The whole FDTD volume consisted of 588×108×298 cells. The ground plane was simulated as an infinitely large perfect conductor, and the transmission line was simulated with its conductivity of 5.8

$\times 10^7$ S/m. Twelve perfectly reflected layers were employed to absorb outgoing scattered waves for simulating an open space.

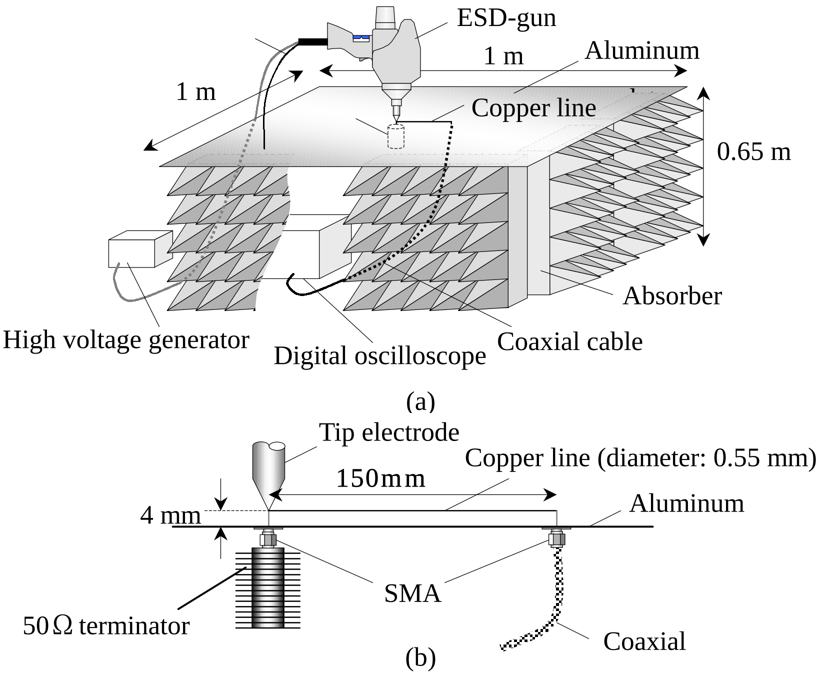

Figure 2 (a) Method of measuring voltage excited to the terminator by discharging to the transmission line and (b) Enlargement of the vicinity of the transmission line.

Figure 2 shows an experimental configuration that was completely identical to the simulation. The transmission line was made of copper, and the ground plane was an aluminum plate. For the both ends of the transmission line, one end was terminated with a resistor of 50 Ω, and the other was connected to a digital oscilloscope with an input impedance of 50 Ω, a frequency band of 1.5 GHz and a sampling rate of 8 GHz.

Figure 3 shows the measured and the FDTD-simulated discharge voltages appearing at the right-hand end of the transmission line. The voltage waveforms during the first 60 ns from the beginning of discharge were shown in Figure 3(a), and those during the first 10 ns from the beginning of discharge were shown in Figure 3(b). The charge voltage V_c was 1 kV. The inductance L of the lumped inductor simulating the switch was determined as 200 nH. In addition, the simulated voltage waveform with L = 0 was also shown in the same figure. Compared to the measured result, a higher peak voltage was observed in the simulated one with L=0. By inserting an adequate inductance L (200nH), the very rapid rise of voltage waveform became gentle, and the FDTD-simulated voltage waveform was found to give a fair approximation to the actual measured voltage waveform. The discrepancies between the simulation and measurement may attribute to the estimation error of the inductance L, the modeling error of the earth return lines, and so on.

4. Conclusion

A simulation technique for ESD-guns is very useful in the design stage of electronic

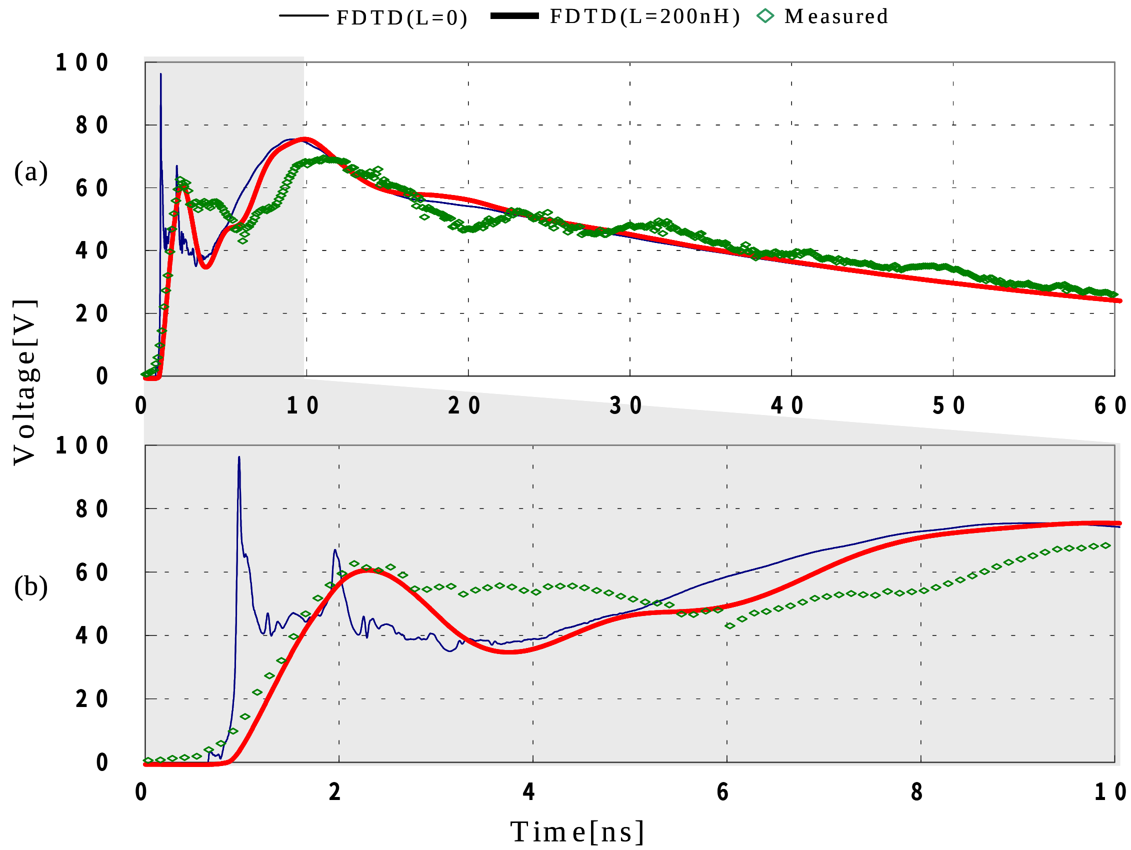

Figure 3 Measured and simulated waveforms of the discharge current injected by an ESD-gun.

products for ESD countermeasure. An FDTD model of ESD-gun has been developed in this study for simulating actual discharge currents. The validity of the FDTD modeling has been verified by comparing the simulated discharge voltage for a transmission line structure with the measured one. The future subject is to improve the simulation accuracy of the FDTD modeling proposed here.

References

[1] JIS C 1000-4-2:1999 (IEC 61000-4-2: 1995/Amd.1),1999.

[2] R. Jobava, D. Pommerenke, D. Karkashadze, P. Shubitidze, R. Zaridze, S. Frei and M. Aidam:"Computer simulation of ESD from volmuminous objects compared to transient fields of humans", IEEE Trans., EMC, Vol. 42, No. 1, pp.54-65, Feb. 2000.

[3] P. Leuchtmann and J. Sroka:"Enhanced field simulations and measurements of the ESD calibration setup", Proc. 2001 IEEE EMC International Symposium, Montreal, Canada, pp.1273-1278, 2001.

[4] G.Cerri, R.De Leo and V.Mariani Primiani:"Theoretical and experimental evaluation of electromagnetic fields radiated by ESD", Proc. 2001 IEEE EMC International Symposium, Montreal, Canada, pp.1269-1272, 2001.