Characteristic Measurement of Transient Current Injected by Air Discharge of an ESD-gun

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Abstract: Electrostatic discharge (ESD) testing is prescribed in the IEC 61000-4-2, which consists of contact and air discharges of an ESD gun simulating the ESD event from a charged human body. The ESD-gun is required to calibrate with the IEC specified waveform injected by the contact discharge onto a specially designed target being called "Pellegrini target". The current waveform for the air discharge, however, is not specified due to bad reproducibility, whose mechanism still remains unclear. In the present study, we measured the discharge currents injected onto the Pellegrini target for the air discharge of a commercially available ESD-gun with respect to its approaching speed to the target. As a result, we found that the fast approach of the ESD gun provides a sharp current with a steeper rise-time and a higher peak, while the slow approach gives a gentle current with the shorter rise-time but lower peak compared to the case for the contact discharge. Furthermore, it was found that there exists a specific relationship between the rise-time and the peak current normalized to the charge voltage regardless of the approaching speed of the ESD gun.
Key words: Electrostatic discharge, ESD-gun, air discharge, approaching speed, discharge current, rise-time, current peak.

1. Introduction

With the high speed and low voltage operation of ICs, the electromagnetic (EM) immunity of electronic devices has been degrading. Especially the transient EM fields due to electrostatic discharge (ESD) events have broadband frequency spectra, which cause serious failure to high-tech information equipment [1-2].

From this perspective, ESD-immunity testing is being specified in the IEC 61000-4-2[3], which consists of contact and air discharges of an ESD gun simulating the ESD event from a charged human body. The former is the way that the current is injected into the equipment under testing (EUT) in contact with the ESD-gun, and the latter is the one that the current is injected through the air discharge into the EUT. The ESD-gun is required to calibrate with the specified waveform injected by the contact discharge onto a specially designed target, which is called "Pellegrini target"[3]. The current waveform for the air discharge, however, is not being specified due to bad reproducibility, whose mechanism has not yet been elucidated. Since actual ESD events occur with sparks, the air discharge testing should be more faithful as ESD events. Thus grasping the behavior of the current injected by the air discharge would be helpful to establish the worst-case ESD immunity testing.

In this study, we measure the discharge currents through the Pellegrini target for the air discharge of a commercially available ESD-gun with respect to its approaching speed to the target. The effects of the approaching speed on the discharge current behavior are also examined.

2. Measurement

Figure 1 shows a measurement set-up for the air discharge of the ESD gun onto the Pellegrini target. As a ground, an aluminum square plate with a size of 1m was placed horizontally at a height of 0.65m from the floor. The target was fixed at the center of the aluminum plate and was connected to a 6-GHz wide-band digital oscilloscope through a 50-Ω coaxial cable. This target is a current transducer, which enables us to observe currents injected onto the input electrode as voltages appearing across a 50-Ω termination load. The ESD-gun was first fixed above the target vertically, and was connected to the

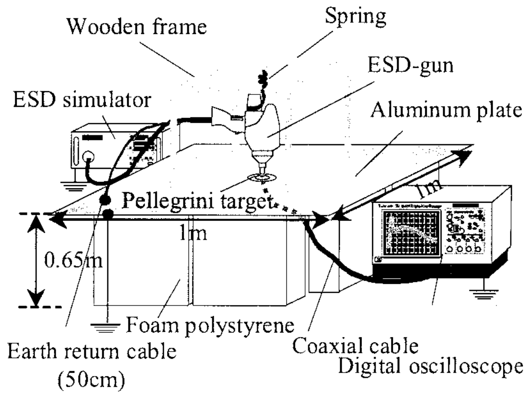


Figure 1 Measurement set-up for air discharge onto the Pellegrini target.

aluminum plate through an earth return cable with a radius of 0.55 mm, which had a length of 50 cm for convenience, although the cable length specified in the IEC standard is 2 m.

An enlarged photo around the tip electrode and target is shown in Fig. 2. As shown in the figure, the ESD-gun was hung with a spring from wooden frame, and was approached to the target at a constant possible speed until the spark between the ESD-gun tip and the target occurred. In this case, two speeds of approach were set: fast approach and slow approach. The former is the way that makes the ESD-gun approach rapidly to the target, and the latter is that making it approach as slow as possible. Current waveforms injected onto the target were observed as voltage waveforms appearing across the termination load of the 50-Ω coaxial cable with a digital oscilloscope (input resistance: 50Ω; bandwidth: 6GHz; sampling rate: 20GHz;resolution: 8bit). 30 times measurements were made for the air discharge at each of the two approaching speeds.

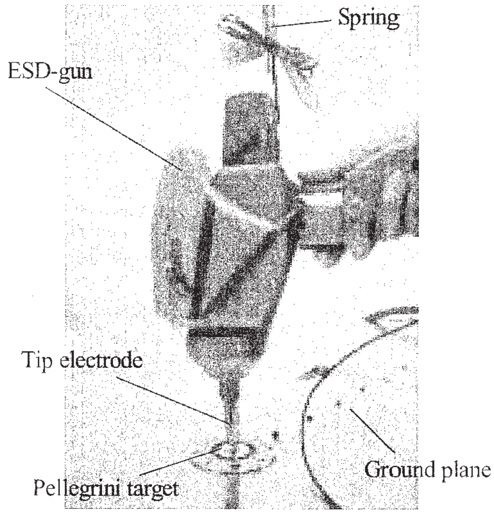


Figure 2 Photo around the tip electrode and the Pellegrini target.

3. Results and Discussion

Figures 3 and 4 show the current waveforms observed for the fast and slow approach of the ESD-gun with discharge voltages of 3 kV and 8 kV, respectively. The abscissa and ordinate indicate time t in ns and current i(t) in A, respectively. The lower figures show enlargements of the waveforms in the upper figures during a period of 0-5 ns. Thick and thin lines in the figures show typical waveforms of the discharge currents having the maximum and minimum first peaks, respectively, among the 30-times observed waveforms. Dotted lines show the current waveform specified in the IEC standard for the contact discharge. It is found from these figures that the approaching speed greatly affects the waveform of the discharge current: the fast approach produces the shorter rise time and higher current peak compared to those for the slow approach. It is also found that in comparison with the case for the contact discharge, the fast approach gives a sharp current with a steeper rise-time and a higher peak, while the slow approach gives a gentle current with the shorter rise-time but lower peak. It should be interesting to note that the current waveforms after 20 ns almost overlap for all the cases.

Figure 5 shows the frequency spectra of the current waveforms observed for the ESD-gun with a discharge voltage of 8 kV, together with the frequency spectrum of the IEC specified discharge current waveform, which were obtained in the following way. Denote by $F(f)$ the frequency spectrum. Then it was calculated simply from

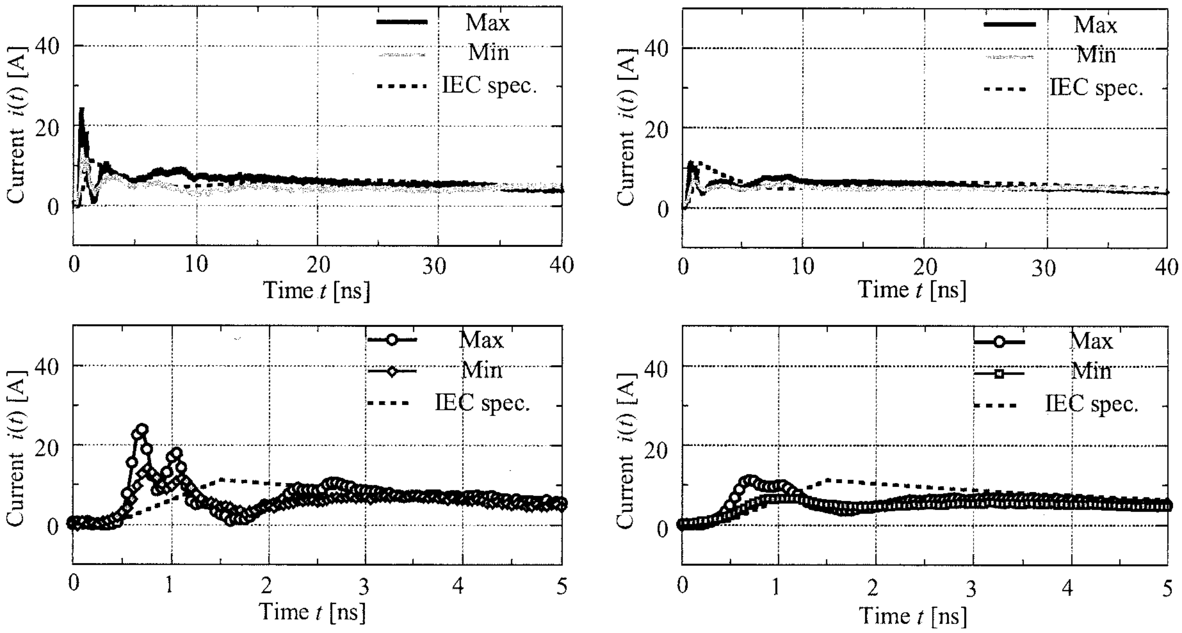
$$F(f) = E\left[\left|\int_{-\infty}^{+\infty} i(t)\exp(-j2\pi ft)dt\right|\right] \quad (1)$$

where $i(t)$ is the discharge current. $E[\bullet]$ means "taking an expectation", which was obtained here as a value averaged over 30-times measurements. As can be seen in the figure, the frequency spectrum for the fast approach has the higher frequency components in the frequency range above 1 GHz, although the frequency spectra below 1 GHz for all the cases seem to be almost the same.

In order to examine the properties of the discharge current behavior with respect to the approaching speeds of the ESD-gun, we obtained from the measured current waveforms the relationship between their rise-time and peak current, which is shown in Fig.6. Also shown in the same figure is the IEC specified relation between the rise-time and the current peak for the contact discharge. The abscissa and ordinate indicate the rise-time t_r and first-peak current I_P normalized to the charge voltage V_c of the observed current waveforms, respectively. Notice that the rise-time and current peaks are given in logarithmic scales. Open and closed circles indicate all the results obtained for the fast and slow approaches, respectively. Large open and closed circles with bars represent "mean ± standard deviation" for the fast and slow approaches, respectively. Gray zone shows the range of the rise time specified in the IEC standard for the contact discharge. Likewise in Figs.3 and 4, Fig.6 demonstrates that the fast approach gives the shorter rise-time and higher current peak compared to those for the slow approach, which gives the shorter rise-time but lower current peak than the case for the contact discharge. The figure also indicates that there is a specific relationship between the rise-time t_r and current peak I_p normalized to the charge voltage V_c regardless of the approaching speeds. An approximated equation for representing the above relation can be expressed as

$$\frac{I_p}{V_c} \propto t_r^{-0.75}, \qquad (2)$$

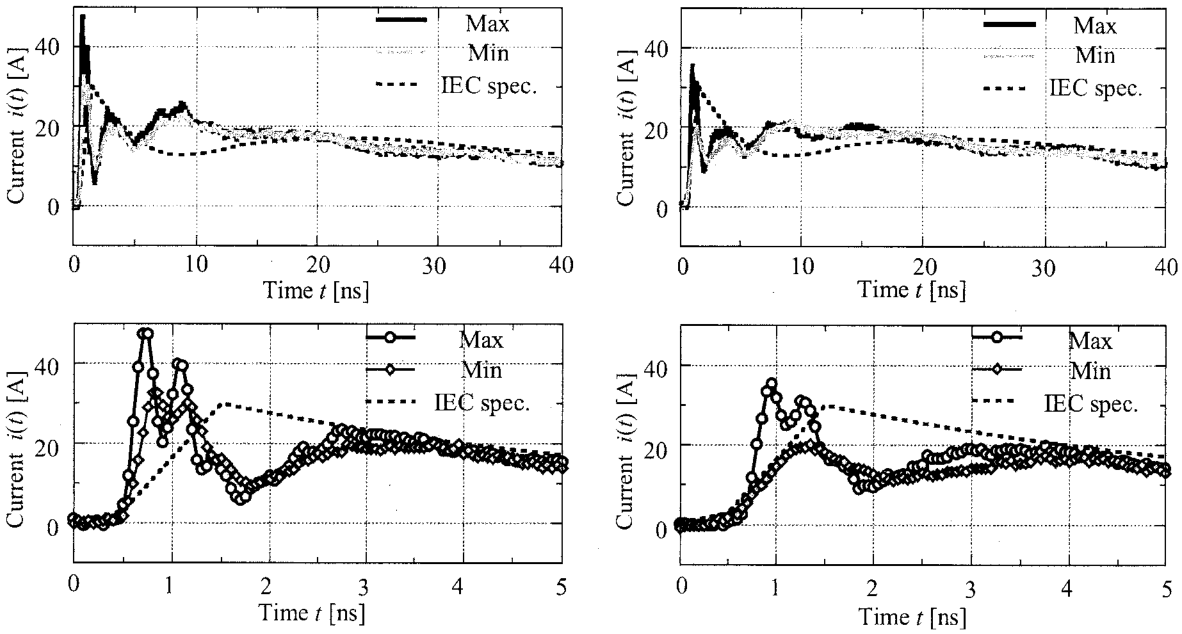
which is shown in Fig. 6 with a solid line. This expression should include the frequency characteristics of the target and digital oscilloscope. Since the oscilloscope has a 6GHz bandwidth, accurate measurement can be done for the waveform with a rise-time of over 100 ps. The target, however, was reported to have a resonance at around 3 GHz for its transfer impedance [4]. For this reason, we previously confirmed that the transfer impedance of



(a) Fast approach

(b) Slow approach

Figure 3 Waveforms observed for (a) fast approach and (b) slow approach of the ESD-gun with a charge voltage of V_C=3kV.



(a) Fast approach

(b) Slow approach

Figure 4 Waveforms observed for (a) fast approach and (b) slow approach of the ESD-gun with a charge voltage of V_C=8kV.

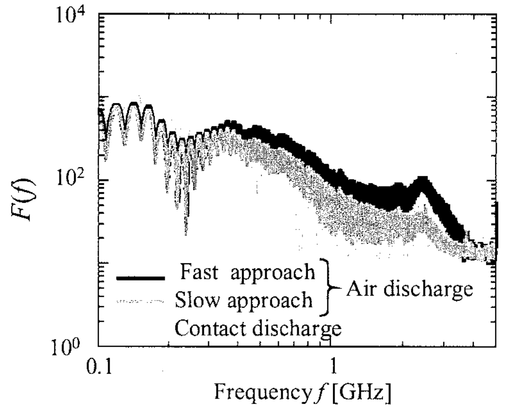


Figure 5 Power spectra of discharge currents (V_C=8kV).

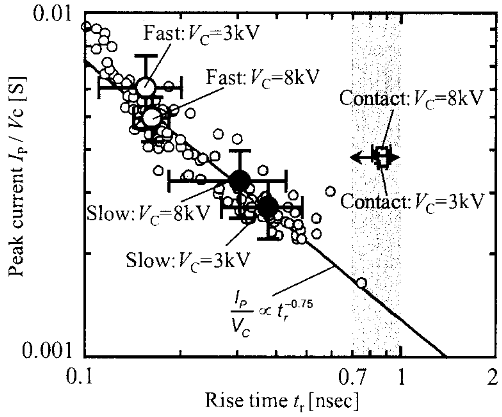


Figure 6 Rise time t_r versus first-peak current I_P.

the target has a flat frequency response below 1 GHz from an FDTD simulation and an experiment [5]. This finding shows that the observed waveform with a rise-time of over 0.35 ns should be identical to the injected current from the ESD-gun via the target, which ensures that Eq.(2) holds for the slow approach. For the fast approach, however, all the obtained rise-times are shorter than 0.35 ns, which needs to modify Eq.(2) according to the frequency response of the target. Nevertheless, the specific relation expressed as Eq. (2) must be helpful to understand the current behavior and available to predict the worst-case ESD immunity testing for the air discharge even though it has poor reproducibility for the injected currents.

4. Conclusion

Wide-band measurement of the discharge currents injected onto the Pellegrini target for the air discharge of an ESD-gun has been done in conjunction with the approaching speed to the target and the charge voltage. As a result, it was found that the approaching speed greatly affects the waveforms of the discharge current with respect to the rise-time and current peak. In comparison with the contact discharge, the fast approach produces the shorter rise-time and the higher current peak, while the slow approach gives the shorter rise-time but the lower peak, which was also confirmed from the frequency spectra of the discharge currents. Moreover, a specific relationship between the rise-time and current peak was observed for the air discharge of the ESD-gun regardless of its approaching speed.

In view of the frequency response of the Pellegrini target, further measurement of the rise-time versus current peak with respect to the approaching speed for the air discharge should be done as a future task.

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