# Statistical Measurement of Burst Discharge Currents through Fingertip from Charged Human

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***Abstract*— To understand the characteristics of human electrostatic discharges (ESDs), using a 12-GHz digital oscilloscope, we measured discharge currents injected into an IEC (International Electrotechnical Commission) current calibration target through the fingertip from a human body charged at a voltage of 300 V. Occurrence frequencies of the current waveforms and their cumulative relative frequency distributions were investigated. As a result, we confirmed that the finger touch causes burst discharges having current peaks of 60-ps rise time but a few ten milli-amperes, while the hand-held metal produces a one-shot discharge of the current peak with five-to-six amperes and 45-ps rise time. It was also found that the fingertip provides discharge peak currents that vary according to a log-normal distribution, while the hand-held metal bar gives current peaks following a normal distribution.**

***Keywords—Electrostatic dischaerge (ESD); charged human body; burst discharges ; discharge currents; statistical characteristics***

## I. INTRODUCTION

Electromagnetic (EM) noises are still severe threat against electronic devices. Especially with the expanding ubiquitous use of high-spec handy information devices, electrostatic discharge (ESD) events accompanied by transient EM fields with broadband frequency spectra are major EM noise source for them [1-4]. In this context, the International Electrotechnical Commission (IEC) prescribes an ESD immunity test as the IEC 61000-4-2 by using an ESD simulator or an ESD gun to simulate ESD current waveforms from a charged human body [5]. The ESD gun consists of a built-in capacitor of 150 pF and a lumped resistor of 330 Ω, which correspond to a human-body capacitance and resistance, respectively. In the above immunity test, charges accumulated in the capacitor are injected into equipment under test (EUT) through a lumped resistor of 330 Ω from the ESD gun. The IEC recommends contact discharge mode, in which the discharge currents are injected into EUT in contact with an ESD-gun at charge voltages from 2 kV to 8 kV. This situation is quite different from that of real human ESDs, in which charges distributed on the surface of a human body should be discharged through a spark. In addition, the lower voltage ESDs have widely been accepted to cause further serious failure or malfunction in high-tech equipment, while its mechanism has not fully been clarified.

To elucidate a generation mechanism of ESDs from a charged human body especially at low voltages below 1 kV, using a 12-GHz digital oscilloscope, we previously measured discharge currents through a 50-Ω SMA receptacle from a hand-held metal bar or a fingertip, and found that the metal bar produces a single-shot discharge, while the fingertip gives multiple-shot discharges [6]. We also found that at several hundred charge voltages the fingertip provides burst discharges, which should cause malfunctions of information devices equipped with ultrahigh-speed and low voltage ICs [7-8].

In this study, to further understand the behavior of the above burst discharges, we measure current waveforms from a fingertip of a 300-V charged human into an IEC current calibration target, and show statistical characteristics of burst discharge currents.

## II. MEASUREMENT METHOD

Fig. 1 (a) shows an experimental setup for measuring discharge current waveforms from the tip of the forefinger of a charged human on an IEC calibration current target, Schaffner: MD 102. A 1m-by-2m aluminum plate was placed as a ground vertically on a square aluminum plate with a side of 1 m. The target was fixed at the center of the vertical plate, and was connected through a 50-Ω coaxial cable to a digital oscilloscope with a bandwidth of 12 GHz and a sampling frequency of 40 GHz. A subject (male, height: 173 cm. weight: 61 kg) stands on 15 mm-thick form polystyrene curved into the shape of shoe soles as an insulator from the ground. After the subject was charged to 300 V through a resistor of 100 MΩ from a DC power supply, the forefinger was approached the target. The approaching speed was taken as an average speed of 20 cm /s, which was defined as the ratio between the moved distance from the tip of the forefinger to the target and time taken to move this distance.

Fig. 1 (b) shows enlargement around the hand and the target when the forefinger approaches the target. When sparks occur between the fingertip and the target, the resultant discharge current waveforms were measured as the corresponding voltage waveforms. Note that the IEC calibration current target has resonance frequencies of around 2 and 5 GHz, which does not affect the observed current waveforms [9]. The measurement was repeated 300 times and measurement waveforms were observed for 800 ns from the beginning of the discharge. For reference, as shown in Fig. 1 (c), discharge currents through a metal bar held by the subject's hand were also measured. In this case, the measurements were repeated 100 times. As a metal bar, a tip electrode for air discharges of an ESD gun was used, whose dimensions are shown to the left of Fig. 1 (c) [5]. The experiment was performed in a room at 25 °C and a relative humidity of 53 %.

## III. RESULTS AND DISCUSSION

Fig. 2 (a) shows typically observed discharge current waveforms for discharges through the tip of the forefinger of a charged human body. Though the discharge lasts for more than 100 µs, the waveform in the range of 800 ns after the first spark occurs is shown in the figure. Fig. 2 (b) shows current waveforms for discharges through a metal bar held by a charged human. In both cases charge voltages are 300 V. In Fig 2 (b), the discharge current waveform from an ESD gun charged to the same voltage is also plotted as a reference, which was obtained by approaching the charged gun in air discharge mode on the target at the same speed. In these figures, the horizontal and vertical axes indicate time in ns and discharge current $i(t)$ in A, respectively. The lower figures are enlargements of the waveforms in the upper in the range of 2 ns after the beginning of the discharges.

From these figures, we can find that the fingertip provides a burst discharge with multiple current peaks, while the hand-held metal bar and the ESD gun provide single-shot discharges. It is also found that though the first current peak of the fingertip discharge is about one-hundredth smaller than that of the metal bar discharge, while their rise time is comparable and below 100 ps.

Fig. 3 (a) shows occurrence frequencies of the discharges (the upper) and their cumulative relative frequency distributions (the lower). The horizontal axes indicate discharge current peaks of the multiple discharge waveforms $I$ in A, and the vertical axes of the upper and lower figures indicate occurrence frequencies $N$ and cumulative frequency distributions in %, respectively. In these figures, solid diamonds, open circles and crosses indicate the first, the second and the third peaks of the discharge current waveform, respectively. Fig. 3 (b) shows the case for the discharges through the meal bar held by a charged human body, which are plotted in triangles. Solid curves in the lower figures (a) and (b) show theoretical values of log-normal and normal distributions for the fingertip and metal-bar discharges, respectively, which will be discussed later.

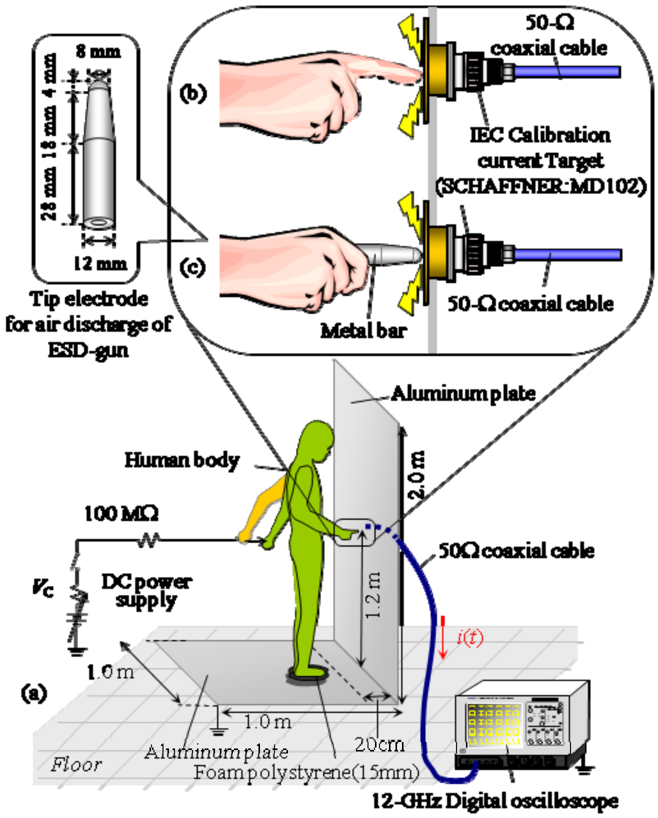
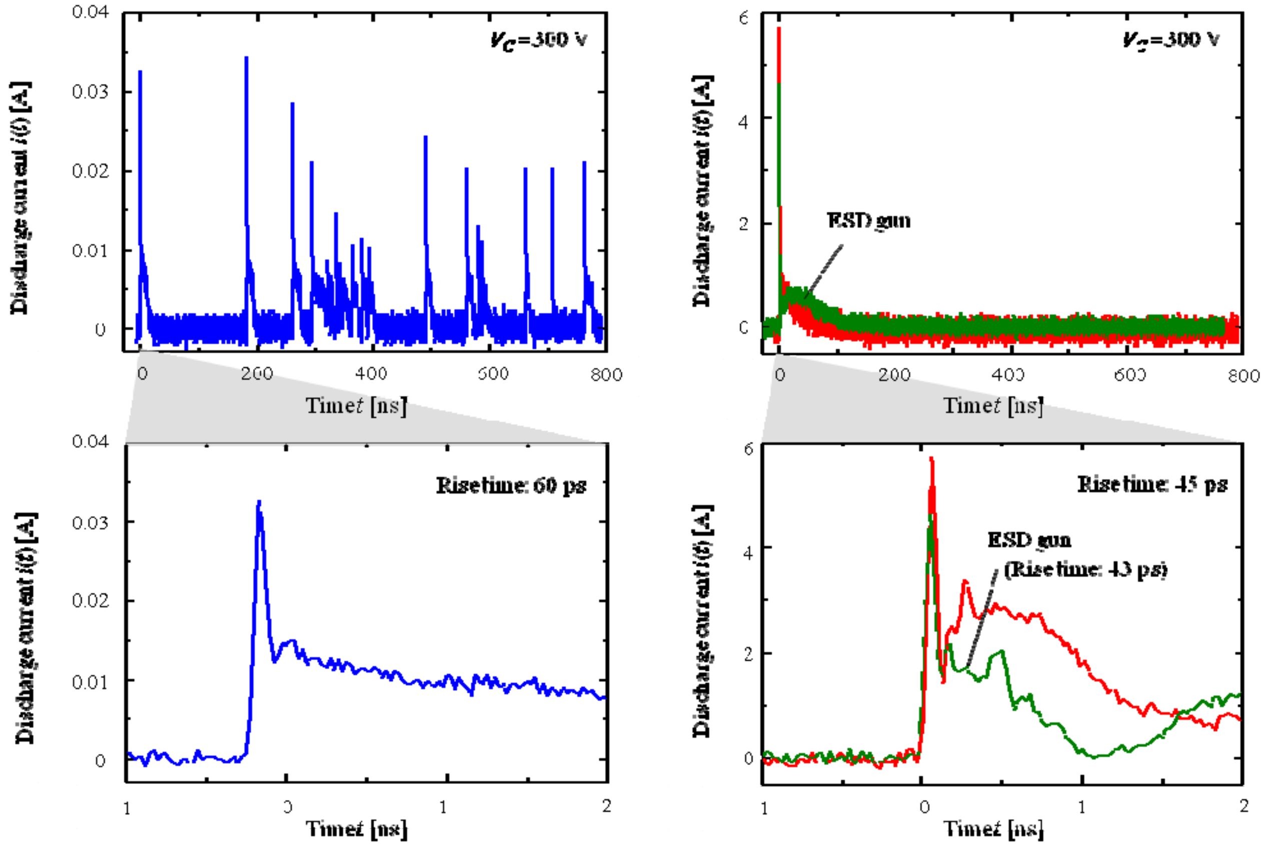



**Fig. 1. (a) Setup for measuring discharge current waveforms from a forefinger of a charged human body onto the IEC calibration current target, (b) enlargement around the forefinger and the target and (c) enlargement in the case of discharges from a metal bar held by a human hand.**

The occurrence frequency of each current peak for the fingertip discharges, shown as the upper figure in Fig. 3 (a), are found to have the same tendency and each peak appears most frequently between 0.015 and 0.025 A. More precisely, according to the cumulative relative frequency distribution in the lower figure, the 50 percentiles of the first, the second and the third peaks are 0.022, 0.02 and 0.018 A, respectively. This indicates that the each peak is the almost same level, and the peak might be also slightly decreasing as the multiple discharges progress. On the other hand, according to the Fig. 3 (b), the one-shot discharge through the metal bar has a peak more than 260 times higher than those of the fingertip discharges and the 50 percentile of its cumulative relative frequency distribution is 5.3 A. 64 % of the current peaks are in the range from 5 to 6 A.

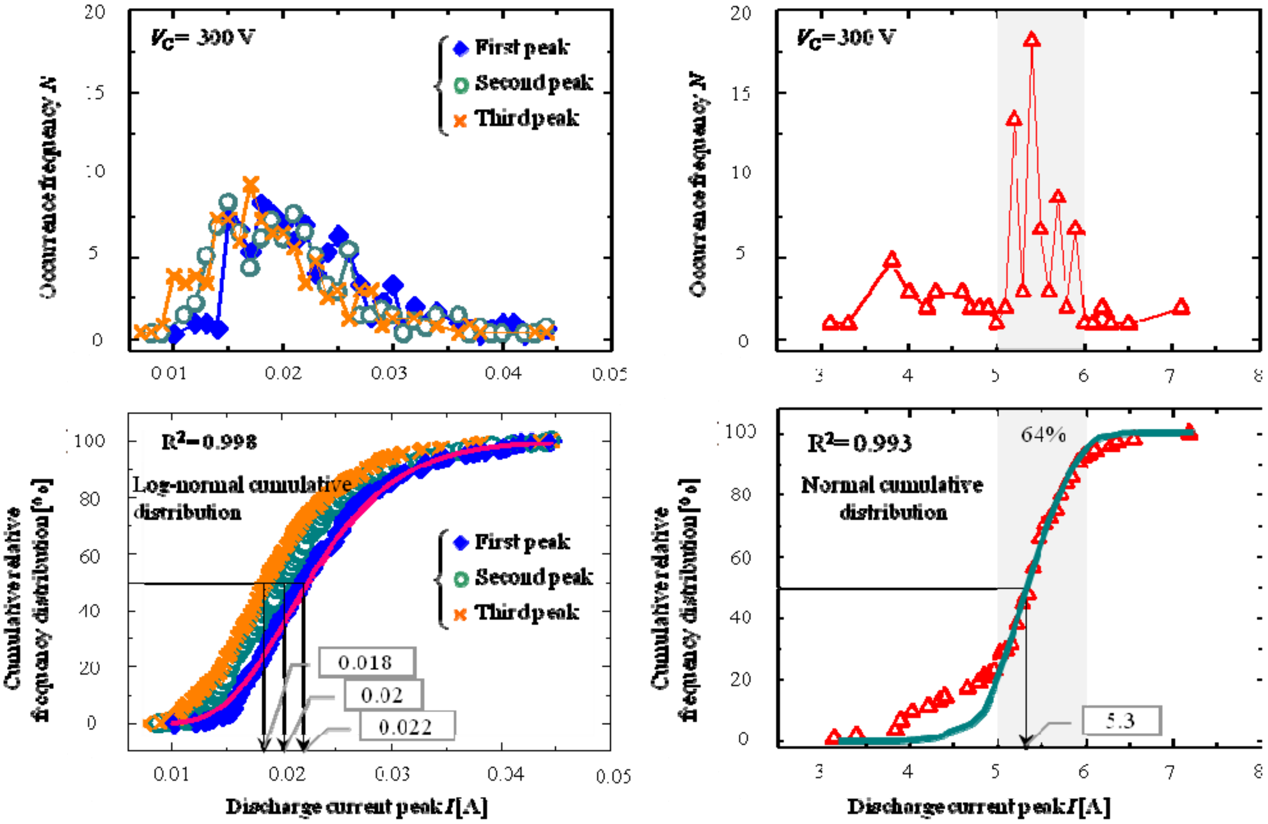
To obtain the statistical properties of the discharge currents, we fitted the measured results in the lower figures 3(a) and 3(b) with theoretical cumulative distribution functions $F(I)$, which were derived from the following equations:

$$F(I)=\begin{cases}\displaystyle\int_0^I \frac{1}{\sqrt{2\pi}\sigma u} e^{-\left\{\frac{(\ln u-\mu)^2}{2\sigma^2}\right\}} du & \text{for log-normal distribution} \\ \displaystyle\int_0^I \frac{1}{\sqrt{2\pi}\sigma} e^{-\left\{\frac{(u-\mu)^2}{2\sigma^2}\right\}} du & \text{for normal distribution.}\end{cases} \quad (1)$$




(a) Fingertip discharge (b) Metal-bar discharge

Fig. 2. Measured current waveforms (a) through the forefinger-tip and (b) through the hand-held metal bar from a charged human body.




(a) Fingertip discharge (b) Metal-bar discharge

Fig. 3. Occurrence frequencies and cumulative relative frequency distributions of discharge currents (a) through the fingertip and (b) through the hand-held metal bar from a charged human body.

Table 1. Mean values and standard deviations of current peaks and peak occurrence intervals.

| | Fingertip | | | Metal-bar |
|---|---|---|---|---|
| | First | Second | Third | |
| Current peak [A] | 0.0232 ± 0.00675 | 0.0213 ± 0.00665 | 0.0195 ± 0.0063 | 5.27 ± 0.701 |
| Occurrence interval [ns] | ———— | 227 ± 206.0 | 331 ± 216.2 | ———— |

Here, $\mu$ is the logarithmic mean ($\mu$ = -3.73) and σ is the logarithmic standard deviation ($\sigma^2$ = 0.32) for the log-normal distribution. For the normal distribution, $\mu$ is the mean ($\mu$ = 5.27) and σ is the standard deviation ($\sigma^2$ = 0.49). The fitting curves agree well with the measured results with the coefficients of determination $R^2$ of 0.998 and 0.993 for the fingertip and metal-bar discharges, respectively.

Table 1 shows a set of the mean values and standard deviation of current peaks and occurrence intervals, which are obtained from (1). It should be noted that 92 % of the second peaks and 86 % of the third peaks are in the range of the mean plus or minus standard deviation. Also note that the occurrence frequencies for the second and third peaks are about 4.4 MHz and 3 MHz, respectively.

## IV. CONCLUSION

To grasp characteristics of human ESD events, we statistically measured discharge currents injected into an IEC current calibration target through the fingertip of a human body charged at a voltage of 300 V. As a result, we confirmed burst discharges caused by the finger touch, which have current peaks of 60-ps rise time but a few ten milli-amperes, and a one-shot discharge due to the hand-held metal bar having the current peak with five-to-six amperes and 45-ps rise time. We also found that the current peaks for the fingertip and hand-held metal discharges vary according to log-normal and normal distributions, respectively. This implies that both discharge mechanisms should be entirely different.

A future subject is to clarify a growing mechanism of fingertip discharges with respect to charge voltages.

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