Human hand/metal ESD and its physical simulation

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Abstract

Human hand/metal ESD is approached as a travelling-wave process, with attention to wave reflection from discontinuities. Human-subject ESD current waveforms and current waveforms computed approximately from swept-frequency impedance measurements illustrate this notion. Time and frequency domain measurements on a physical simulator are presented for comparison.

1. Introduction

The use of high speed logic makes modern electronic systems extremely susceptible to human electrostatic discharge (ESD). Over the past decade, serious attention devoted to the problem of ESD-related failures in systems has yielded a number of standards. The IEC 801-2 standard, which defines the "human hand/metal ESD current waveform", recommends that the ESD current waveform be applied to equipment to verify its ESD immunity. Simulators have consequently been designed which produce the required ESD waveform and are currently being used in industry for ESD testing purposes.

Most of the commercially available ESD simulators, however, are made up of lumped elements. The human body, at high frequencies, behaves as a distributed system and hence human ESD must be viewed as a travelling wave process [1]. Lumped element ESD simulators cannot simulate a transient travelling-wave event. The subject of this paper is therefore the study of human hand/metal ESD as a travelling-wave process, with attention to wave reflection from discontinuities in the arm, and the physical simulation of ESD by creating a simulator made of continuous and lossy material. The simulator is shown to produce extremely repeatable discharge waveforms.

2. Measured time-domain human hand/metal ESD waveforms

A Tektronix 7250 transient digitizing oscilloscope with a bandwidth of 6 GHz was used to capture the physical discharges. The 75 ns delay line that was used in the experiments reduced the overall bandwidth of the system to 3 GHz. The measurement system is, therefore, capable of resolving pulses with rise times as short as 116 ps. The human subject discharged into a 1 ohm current monitoring resistor (CMR) which was grounded to a large aluminum plate as shown in Fig. 1.

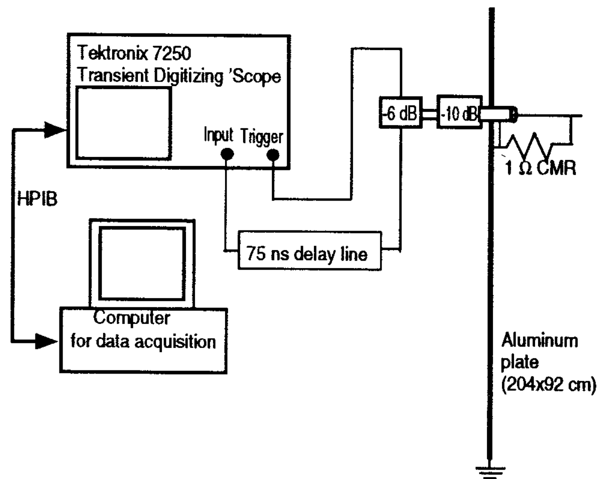

Figure 1. Experimental setup for time domain ESD current waveform measurements.

The subject was charged to the desired voltage by using a high voltage power supply. The power supply had a large resistor at its output to limit the current. The voltage on the body was also checked using a Trek HV340 electrostatic voltmeter. The subject held an average-length screwdriver in his hand ensuring that the side of the index finger and the tip of the thumb were in firm contact with the shank. With the arm outstretched (i.e. arm perpendicular to the body), the subject (standing on a crush-resistant foam to prevent charge leakage through the soles of the shoes) brought the tip of the tool slowly towards the CMR until a discharge occurred.

Considering the human arm as a lossy transmission line, one would expect to see a reflection from the discontinuity represented by the arm/shoulder junction. Assuming that the generated current wave propagates

:lose to the speed of light in vacuum, with the tool used, he expected return time of the reflection is around 5 ns ıfter the occurrence of the main peak. If the subject)ends his arm at the elbow and then approaches the CMR ıntil he discharges, then one would also expect to see 'eflection from the elbow and the expected return time of his reflection would be around 3 ns (again after the)ccurrence of the main peak). Figure 2 shows 1 kV dis-

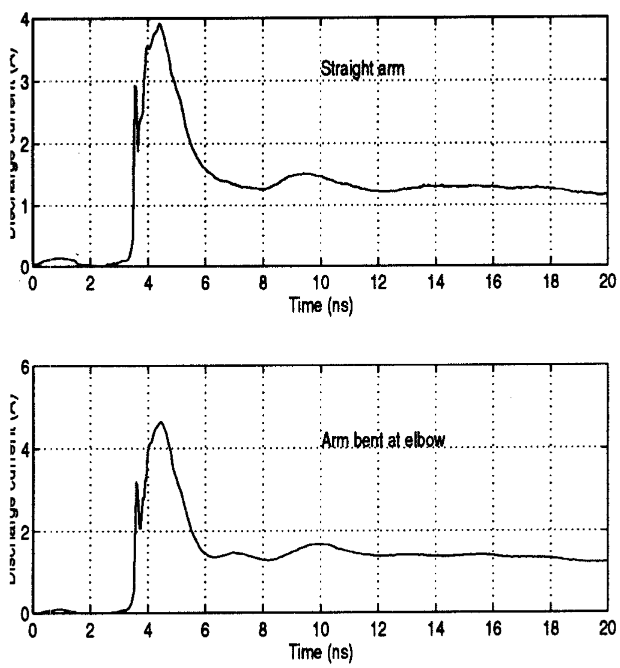

Figure 2. 1 kV human hand/metal discharges.

:harges, with the arm outstretched and with the arm bent ıt the elbow. One can clearly see the peak at around 9.5 ıs (in the straight-arm case) corresponding to the reflec- ion from the shoulder, and in the case of the arm bent at he elbow, two peaks can be seen at 7 ns and 10 ns corre- ;ponding to reflections from the elbow and shoulder 'espectively.

Changing the length of the tool in the subject's hand :hanges peak current and pulse width, for a given charge ıp voltage. Figure 3 shows a 1 kV discharge of a human ;ubject discharging through a 1.77 cm long brass rod (the ;crewdriver used to generate discharge waveforms in Fig. ? had a shank length of 7.95 cm). As can be seen by :omparing Fig. 2 (straight arm case) and Fig. 3, more netal in the discharge path yields discharge waveforms with increased pulse widths. Discharging through the ;horter brass rod yields a higher peak current than dis- :harging through the longer screwdriver. The peak seen n Fig. 3 at 8 ns corresponds to the wave reflection off the

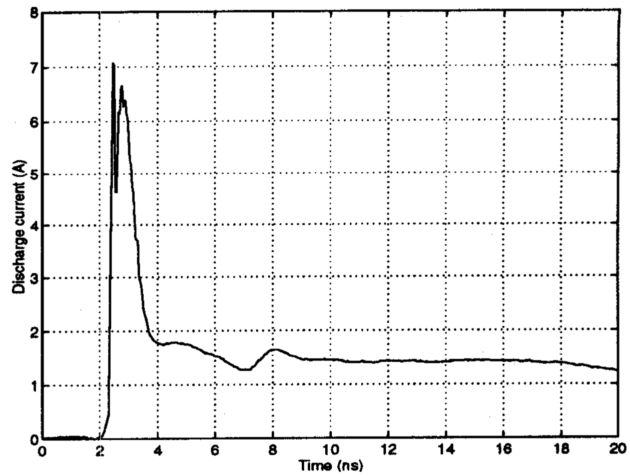

Figure 3. 1 kV discharge of a human subject holding the brass electrode.

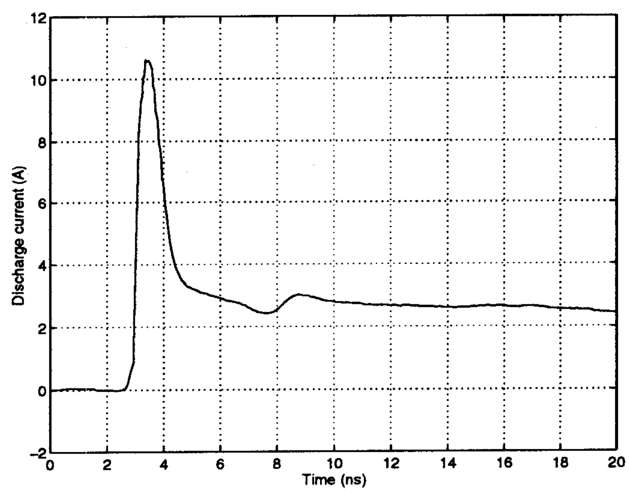

Figure 4. 2 kV discharge of a human subject holding brass electrode.

shoulder.

Looking at the 1 kV discharges, one sees that after the initiation of discharge, the first nanosecond or two is associated with oscillations. To see whether this oscillatory effect is seen at higher voltages as well, 2 kV discharges were performed with the brass rod (a sample discharge is shown in Fig. 4). In this case, however, no oscillations are seen. Discharges at higher voltages performed with the screwdriver also show no oscillations. Hence, based on observations, one can make the claim that low voltage discharges (~ 1 kV) exhibit slight ringing following the initial spike. Another observation that can be made is that low voltage discharges have shorter rise times than their high voltage discharge counterparts. From an EMC standpoint it can be easily concluded that low voltage discharges could be a more serious threat to modern electronic systems than high voltage discharges. This point was first made by Honda [2].

3. Simulator design

A travelling-wave ESD simulator was originally designed by Balmain and Rayal [1]. However, this device simulated a bare finger discharge. Commercially available ESD simulators, however, simulate a human hand/metal ESD as it is considered to be the worst case for ESD testing [3]. Thus the original prototype designed in [1] was modified for hand/metal simulation.

Figure 5 shows the details of the simulator made of lossy dielectric material Eccosorb VF-60. The material is

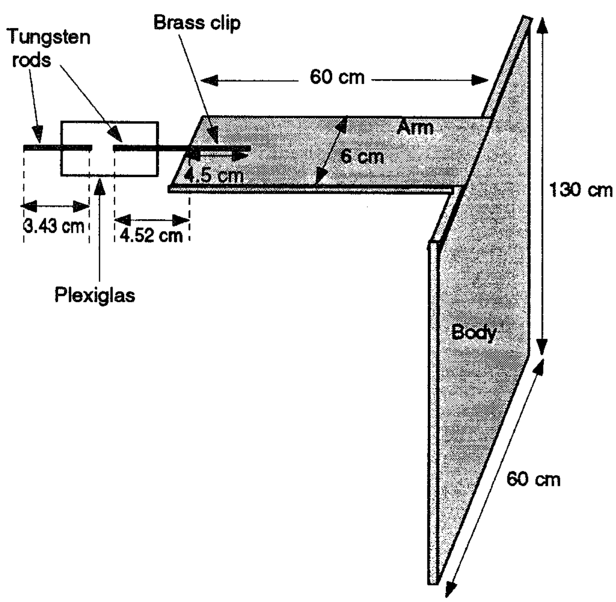

Figure 5. Travelling-wave ESD simulator (not to scale).

60 mils (0.1524 cm) thick. The simulator consists of a "body" (130x60 cm), an "arm" (60x6 cm) and an adjustable air gap arc cell (two tungsten rods separated in air). As the name suggests, the air gap between the discharging electrodes can be adjusted to allow for discharging of the simulator at various voltages. To measure the discharges from the simulator, the free end of the arc cell is put in contact with the 1 ohm CMR of Fig. 1.

To simulate discharges, the air gap is ensured to be of sufficient width so as not to initiate a discharge. The "body" is charged up to the desired voltage and the tungsten electrodes are brought toward each other until a discharge occurs. Once the breakdown gap for a particular voltage has been established, subsequent discharges can be initiated without human intervention near the discharge site.

3.1. Comparison of simulated and human hand/metal discharges

Figures 6 and 7 show a comparison of human hand/metal and simulator discharges at 1 and 2 kV respectively. As can be seen from these figures, the simulator

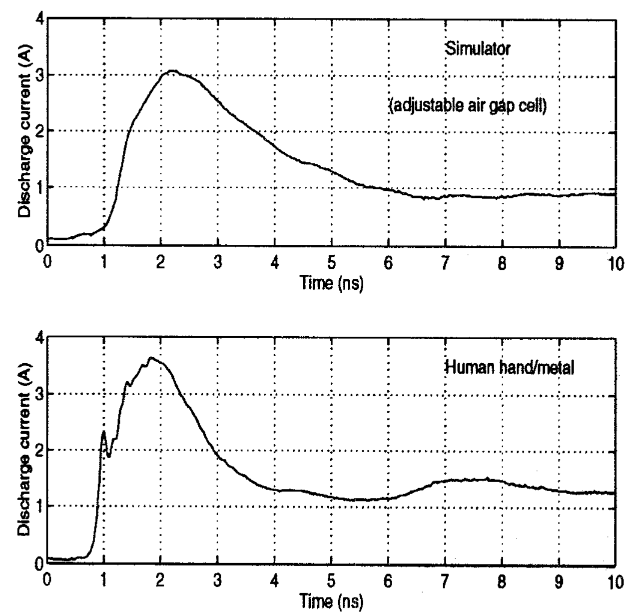

Figure 6. Sample of 1 kV discharges.

material is capable of generating the same peak current as in the human hand/metal case. Also, the rise times and the pulse widths are quite comparable. In the simulator case, however, reflection off the "arm"/"body" junction is not seen because the simulator "arm" has a greater attenuation than the human arm. Still, on the whole it can be said that the simulator produces discharge waveforms which are quite similar to those generated by the human hand/metal case.

3.2. Repeatability issues

A good ESD simulator would be one that not only

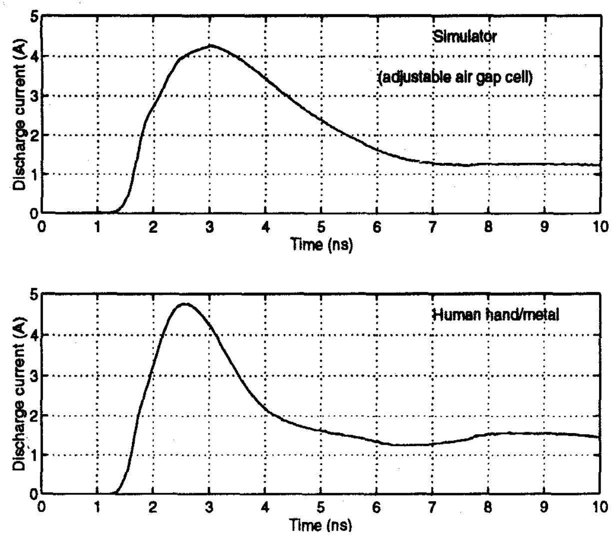

Figure 7. Sample of 2 kV discharges.

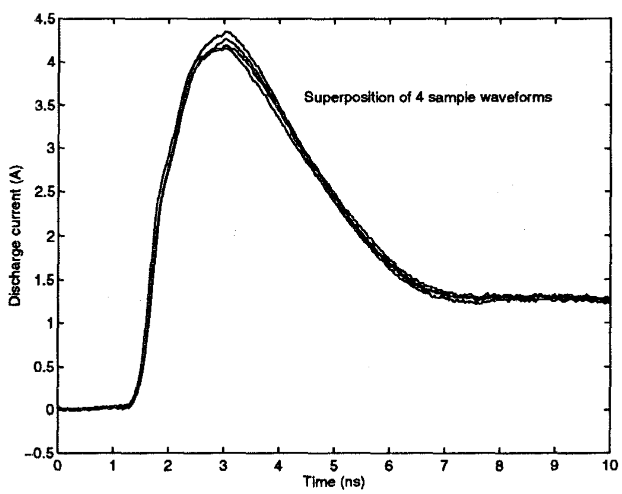

Figure 8. 2 kV discharge waveforms as produced by the simulator.

produces a discharge waveform similar to the one exhibited by the human case, but also one that is highly repeatable. The simulator was tested at various voltages and was found to generate extremely repeatable discharge waveforms. Figure 8 displays 2 kV discharges from the simulator. In this case, four waveforms have been superimposed on the same graph. It can be clearly seen that the simulator's discharges are highly repeatable.

4. Swept-frequency impedance measurements

Figure 9 shows the measurement setup employed to measure the impedance between the tip of the hand-held tool/simulator and the ground plane. The impedance was measured for frequencies in the range 1.874 MHz to 3 GHz. The highest frequency looked at was 3 GHz because the time-domain measurement system had a bandwidth of 3 GHz.

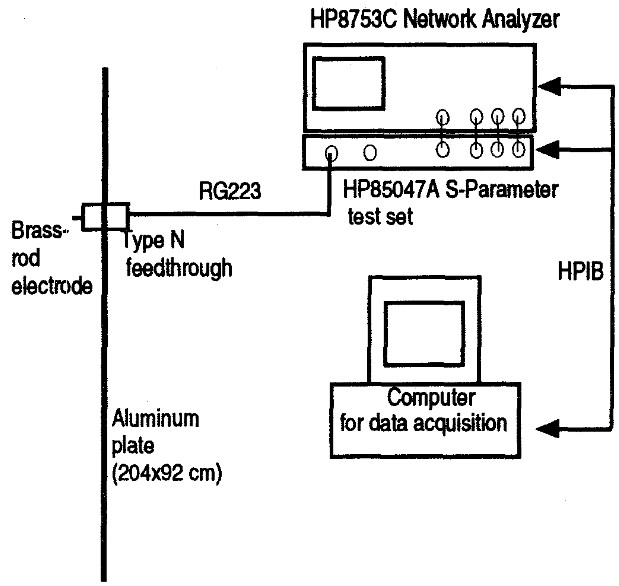

Figure 9. Experimental setup for impedance measurements.

Swept frequency impedance measurements are useful because the discharge current waveform is a strong function of the impedance as seen at the arc site. For this purpose, impedance measurements were performed on both the human hand/metal combination and the simulator. Figure 10 shows the measurement results for the two cases and as can be seen, the two are quite comparable. The human impedance measurement, however, is quite oscillatory compared to the simulator measurement indicating once again that the simulator "arm" has greater losses than the human arm, which is why in the time-domain discharges, reflection off the simulator "arm"/ "body" junction was not seen.

At low enough voltages, an arc can be considered to act as a switch whose closure (physically representing air-breakdown) reduces the voltage suddenly from a high to a low value. This is roughly equivalent to the application of a voltage step, and the step response can be calculated from the impedance measurements. The network analyzer used in these experiments has an internal capability of mathematically computing the step response, from impedance measurements, by using FFT techniques. Step response is useful, especially in the human

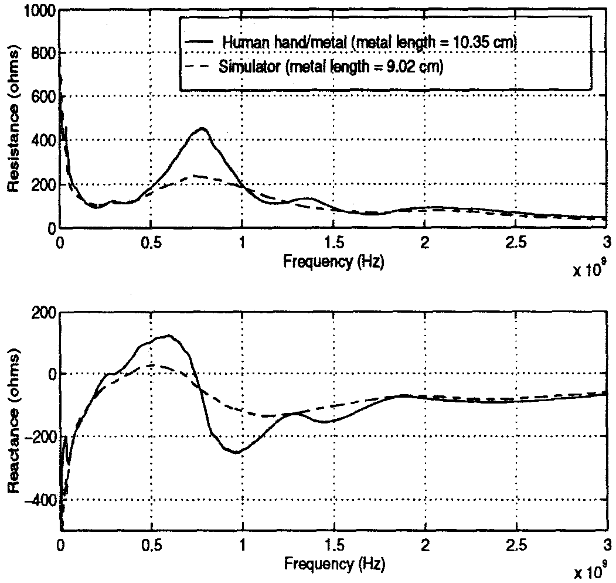

Figure 10. Swept-frequency impedance measurements.

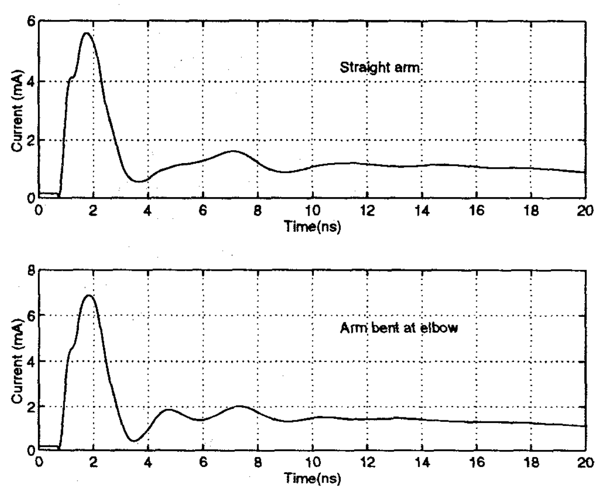

Figure 11. Step response of a human subject holding a screwdriver.

hand/metal case, to see whether wave propagation effects, in terms of appearance of wave reflections off the discontinuities in arm in the current waveform, are visible in the impedance measurements as well.

Figure 11 shows the step responses of the human subject holding the screwdriver. Two cases are displayed, one in which the arm is outstretched and one in which the arm is bent at the elbow. This figure is quite comparable to Fig. 2 (displaying corresponding physical discharges). In the straight arm case, a single hump is seen at around 7 ns corresponding to wave reflection off the shoulder while in the case of the arm bent at the elbow two sub-peaks can be seen corresponding to the reflections off the elbow and shoulder respectively. This implies that step responses can be employed as a useful tool in the study of human ESD, especially at low voltages (~ 1 kV).

5. Conclusions

The human hand/metal ESD has been considered as a travelling-wave event. Major discontinuities in the arm (shoulder, if the arm is outstretched or elbow and shoulder, if the arm is bent at the elbow) cause reflections of the generated current wave which show up as small peaks in the discharge current waveforms.

A travelling-wave ESD simulator, made of continuous and lossy material, has been designed which comes quite close to simulating the human hand/metal ESD. This was substantiated by comparisons made in both time and frequency domains. The simulator has also been shown to produce extremely repeatable discharge waveforms and hence can be employed in industry as a tool to evaluate the ESD immunity of systems.

6. References

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7. Acknowledgments

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