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An Investigation of Human Body Electrostatic Discharge

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Abstract

The electronics industry has recognized the significance of Electrostatic Discharge (ESD) as a potential source of damage, especially to semiconductor devices, for some time. During that time, there has been an ongoing effort to develop a meaningful human body ESD pulse and equipment which is capable of repeatedly applying that pulse at various voltage levels to a semiconductor device. The intent was to determine a part's ability to withstand an ESD pulse at a certain voltage level and use that information as an indicator of the part's robustness. Presently, available equipment is capable of applying an ESD pulse frequently described in specifications such as MIL-STD 883C as the human body pulse; but is this the right pulse? Recent technical papers have raised some interesting questions about the ESD waveform and methods for capturing this waveform. Specifications such as IEC 801-2 have also contributed to the apparent confusion on ESD waveforms and, together, these sources of information were the catalyst that stimulated this investigation.

TODAY'S ELECTRONICS INDUSTRY applications place an increasing number of requirements upon systems and component devices: semiconductor packaging and feature size is smaller, power requirements and operating temperatures are higher, and reliability demands have increased significantly. Designing for the elimination of early life device failures is a key factor in meeting these reliability requirements.

Electrostatic discharge (ESD) events are recognized as a significant contributor of early life failures and failures throughout the operating life of a semiconductor device. Although present integrated circuit designs include ESD protection circuitry, the effectiveness of this protection must be determined in a manner which will ensure its effectiveness in the "real world" if the part is to meet the reliability requirements of the application.

ESD has been studied for some time, and there is reasonable agreement on three (3) models for this phenomena: The Human Body Model (HBM), Machine Model (MM), and Charged Device Model (CDM). In this paper, we will be focusing on the HBM and some concerns we have about the model as presently defined.

Under various conditions, the human body can be charged with electrical energy and transfer that charge to a semiconductor device through normal handling or assembly operations. To evaluate the effectiveness of the protection circuitry in an integrated circuit, HBM ESD testing is performed. This HBM pulse is intended to simulate the human body type ESD conditions the part would experience during normal usage. The ESD testing is also used to determine the immunity or susceptibility level of a system or part to the HBM ESD event. Several different Human Body Model (HBM) ESD simulation circuits and pulse waveforms exist, including Military Standard MIL-STD 883C [1] (see Figure 1), International Electrotechnical Commission (IEC) 801-2 [2] (see Figure 2), and others.

The basic objective of this paper is to explore the following question: Do the present test specifications dealing with the human body ESD event define a realistic ESD threshold or level of immunity, for a system or part in the real world? While the human body ESD waveform has been a topic of research for many years, studies by Hyatt and Mellburg, "Bringing ESD Testing Into The 20th Century" [3]; Mellberg, Sanesi, and Hish, "Recent Developments In ESD Waveform Evaluation" [4]; and Fisher, "A Severe Human ESD Model For Safety and High Reliability System Qualification Testing" [5] have sparked our interest into the actual human body ESD event and waveform characteristics.

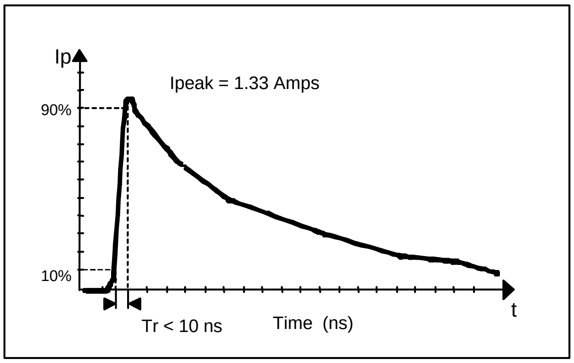

Figure 1: Mil-Std 883 Human Body Waveform (2kV)

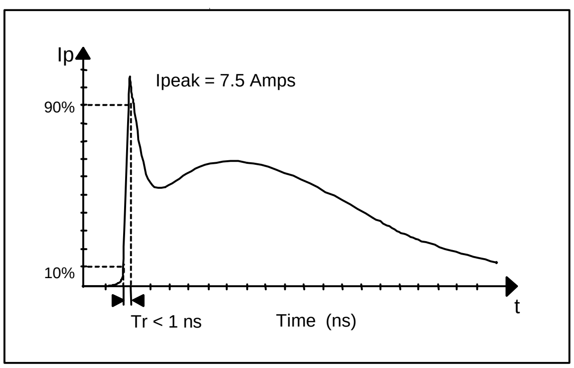

Figure 2: IEC 801-2 Human Body Waveform (2kV)

To investigate the human body ESD event, a study of the actual human body discharge was performed in the laboratory. The intent of the investigation was to gather a basic understanding of the HBM ESD event and stimulate thought about the actual human body discharge pulse and the possible effect on ESD immunity or susceptibility at the part level.

Limitations of Present ESD Methods

A discrepancy appears to exist between reality, measured reality, and common practice as defined in some industry specifications. We feel a universally accepted specification defining the actual human body waveform is not presently available due to various factors including:

1. The non-uniform conditions involved in the ESD environment.
2. The unpredictable circumstances of the ESD event.
3. The constant improvement in test equipment used to study the ESD event.
4. Supplier community resistance to adopting new standards that would indicate some currently used protection circuits are inadequate.
5. Lack of a standardized procedure for capturing the ESD event. Some procedures use measurement techniques that are not capable of capturing the high frequency content or fast risetime of the waveform.

Previous investigations into ESD testing have resulted in two conflicting philosophies. One philosophy states, "the test procedure must look like a human ESD spark...including all variability observed in natural ESD phenomena" [3]. The second testing philosophy is to choose a representative waveform from the range of likely ESD events and generate an instrumentation approach to ESD testing [3]. This latter ESD testing philosophy employs test systems designed to produce a consistent and repeatable ESD waveform.

The difficulty with ESD test systems has been the inability to deliver the relatively fast risetime associated with the surface charge stored on the human body. Many test systems incorporate lumped time constant circuitry and are plagued by parasitic inductance, resistance, and capacitance of the various components. These parasitics can greatly affect the response of the ESD test system and therefore result in invalid ESD event risetimes. The measured risetimes are also limited by the capabilities of the measurement equipment used to capture the ESD event waveform. When the MIL-STD 883C testing procedure was released in 1989, the risetime stated as less than 10 ns may have been accurate for the type of equipment available for waveform verification. Measurement equipment presently available is capable of detecting and capturing ESD waveforms with risetimes as fast as a few hundred picoseconds.

Electrostatic Charging

When two objects come in contact with each other, the triboelectric action between them can generate an electrical energy charge that initiates an ESD event. The sudden release of generated charge in an object or person can produce extremely high voltages, currents, and electromagnetic fields that can result in malfunctioning, altering of device parameters, or even destruction of silicon junctions. In an ESD event, the human body can reportedly generate static charge levels as high as 15,000 volts by simply walking across a carpeted floor and 5,000 volts by walking across a linoleum floor. The potential difference between a charged human body and an object retaining an insignificant charge can range from a few hundred volts to as high as 30,000 volts [6]. We tend to think these reported charge levels are exaggerated due to the measurement errors reported by Ryser [7]. When a charged individual comes in contact with a device or system, a transfer of the stored energy occurs to the device or through the device to ground.

The typical ESD event has a fast, high current peak followed by a lower, more slowly decaying current pulse. The total energy in an ESD event can be tens of millijoules with time constants measured in picoseconds and several kilowatts of power [8]. With this amount of energy available, it is quite evident how a single ESD event can result in a device failure or possibly initiate a device weakness that can cause failure with continued use.

Recent research on human body ESD events shows that discharge pulses with fast risetimes, on the order of 1 nanosecond or less, are the most disruptive to the normal operation of electronic equipment [5]. Therefore, ESD test systems using a fast risetime pulse will more accurately simulate the human body discharge events frequently encountered. Measurement of these parameters has been difficult due primarily to the short time interval, large potential differences, and the measurement bandwidth required to capture both the amplitude and frequency characteristics of the ESD event. These limitations may cloud the issues of ESD susceptibility levels and environmental factors which may protect or damage electronic devices.

The simplest human body ESD model is the series RLC circuit shown in figure 3 in which the R corresponds to the body resistance, L is the corresponding body inductance, and C is the capacitance of the body with respect to its surroundings. The body inductance is often neglected, as in MIL-STD 883C, while a body capacitance of 100 to 250 pF and body resistance of 1000 to 2000 ohms is generally used. Recent developments in the human body ESD model suggest that the closet approximation to an actual human body ESD event may be the worst-case short circuit discharge waveform, documented by Fisher [5] and shown in figure 4, where the parameters are as follows: Rcharge = 1 M , Cbody = 60 to 300 pF, Rbody = 150 to 1500 , Lbody = 0.5 to 2 H, Chand = 3 to 10 pF, Lhand = 0.05 to 0.2 H, and Rhand = 20 to 200 . The equivalent circuit for the worst-case scenario, the body-metallic object model, is found to produce a waveform almost identical to the actual human body discharge pulse captured during the investigation we performed in the laboratory.

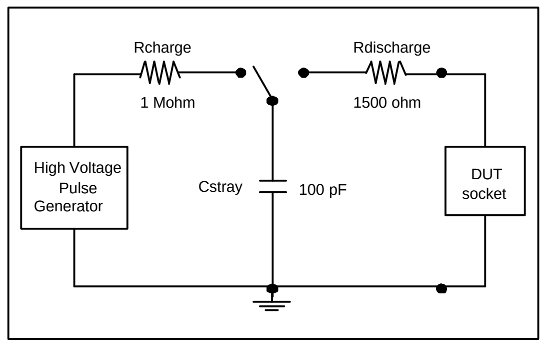

Figure 3: Typical HBM equivalent circuit

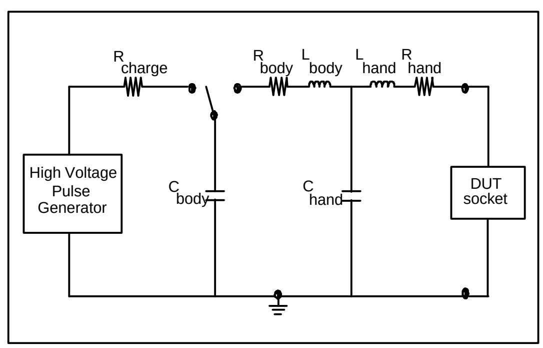

Figure 4: Worst case, actual HBM equivalent circuit

Investigation Procedure

Before an investigation into the human body ESD event could begin, the equipment used to capture the discharge waveform must be understood. Most specifications require the use of an ESD target, or current sensing transducer, to capture the human body ESD waveform. This procedure involves connecting an ESD target to a digital signal analyzer or oscilloscope through low loss cables and having a charged "body" discharge by making physical contact with the target.

Due to the various ESD targets currently available, a greater understanding of each target and all corresponding characteristics was necessary. A study by Mellberg, Sanesi, Nuebel and Hish [4] evaluated the performance of several ESD targets including the Pellegrini, Electro-metrics, Mellberg-Hyatt, and Reynolds-King versions. All targets were characterized by measuring insertion loss, impedance, voltage standing wave ratio, and reflection (time domain reflection). Based on the evaluation results, the Pellegrini type target was chosen. Another study [9] recommends the use of a non-inductive current shunt which adds very little impedance into the ESD discharge path. The study also states the Pellegrini probe introduces a front surface cavity that distorts the local fields from a changed body prior to discharge. The result of the distortion produces the dip seen on the IEC 801-2 waveform (see figure 2).

Because the Pellegrini target was more readily available, it was chosen for waveform measurements in our investigation. The information presented in the Hyatt study [9], however, should be taken into consideration and researched further in order to develop a consensus on the correct measurement target to be used.

The CT-1 current transducer, as specified in the MIL-STD 883C method, was also used to capture ESD events. As will be shown later, the parasitic inductance that is introduced by the CT-1 probe into the ESD discharge path results in a measurement that indicates slower risetimes and dampened first peak amplitude characteristics.

In order to minimize errors with environmental conditions, all testing was performed in a controlled environment room which maintained temperature and humidity at relatively constant levels of 23 +/- 4°C and 32 +/- 5% relative humidity. All human body ESD events were captured using a 1 GHz real time bandwidth digital signal analyzer with a 2 Gigasamples/second sampling rate and utilizing the Pellegrini (1984) target as described in the IEC 801-2 standard. The measurement equipment setup also included a 36" x 18" x 3/8" (L x W x H) insulating glass plate, high voltage power supply, ESD simulator source, and several metallic rods to be used as charge/discharge probes. The Pellegrini target was centered in a 1.5 meter square ground plane and connected to the Digital Signal Analyzer through a 20 dB attenuator.

Several individuals of various height, weight, and gender were used as test subjects during the investigation. One at a time, each "test subject" held a metallic rod (charge/discharge probe) firmly in one hand and stood on the glass insulating plate. The test subject was then charged to a voltage potential by touching the metallic rod to a current limited high voltage power supply. Once the individual was saturated at a voltage potential, approximately 5 to 10 seconds, the metallic rod was removed from the power source and the charged subject was discharged into the target. Test subjects were asked to discharge into the Pellegrini target using the metallic rod and again using their finger tip.

A typical 2000 volt (2 kV) discharge waveform using the metallic rod is shown in Figure 5, while the discharge waveform using a finger tip is shown in Figure 6.

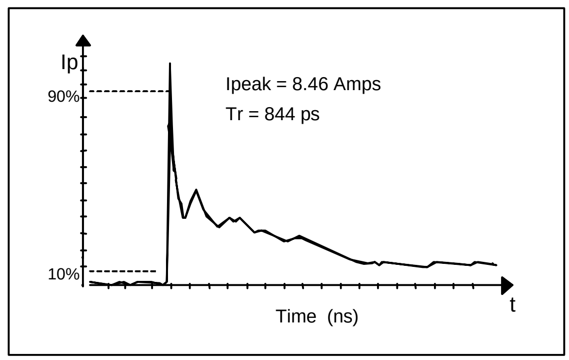

Figure 5: HBM discharge waveform, 2 kV charge metallic rod

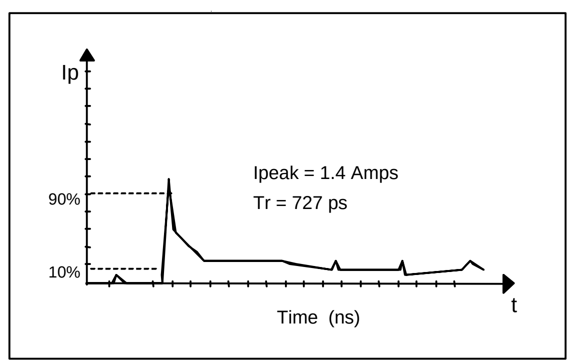

Figure 6: HBM discharge waveform, 2 kV charge finger tip

The outstanding feature of these actual human body ESD waveform measurements is the fast, high amplitude initial peak followed by a secondary peak of lower amplitude, significantly slower risetime, and longer dwell time. The observed first peak occurred in 800 to 1700 picoseconds, followed by a decay (20% of first peak to zero) of approximately 100 nanoseconds. The first peak amplitudes for a 2 kV potential were measured and found to vary between 5 and 12 Amps, depending on the individuals being charged.

Although the test subjects ranged from 125 to 325 lbs in total body weight and from 5'3" to 6'5" in height, no relationship between body size/shape and discharge peak amplitude was observed. Individuals that tended to be on either extreme of the height and weight range resulted in the lowest discharge waveform parameters (risetime and first peak amplitude). The human body ESD event is therefore believed to be dependent upon skin-surface resistance and/or body chemistry. To fully understand the relationship between the HBM ESD event and the characteristics of the human body, further investigation is required.

The test subjects were then charged to a 2 kV potential and discharged using various metallic rods: steel, brass, and a thin stainless steel screwdriver (see Figure 7). The observed ESD waveforms were similar to the waveform of Figure 5.

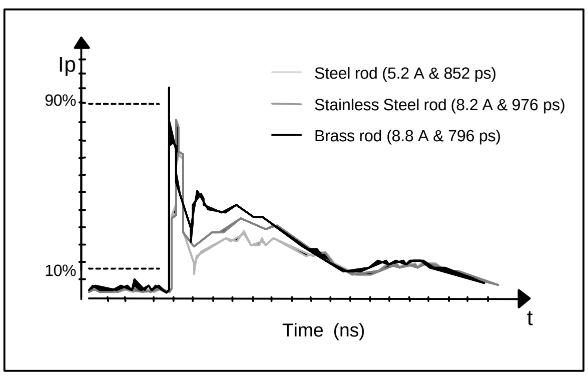

Figure 7: Discharge waveforms for a 2 kV charge, various metallic rods

The brass rod seemed to result in the highest first peak amplitude, followed closely by the steel rod. The different metallic material of each rod had little to no effect on the first peak risetime, therefore showing the risetime is dependent upon the individual or "body" being discharged.

Next, the test subjects were charged to a voltage potential using several sources: a high voltage power supply, an ESD simulator, and a 500 pF capacitor (see Figure 8). Again, the discharge waveforms resembled the typical waveform of Figure 5, showing the human body ESD event is not dependent upon the charging source.

In order to examine the effects of higher voltage potentials, test subjects were charged to 8 kV and discharged into the Pellegrini target (see Figure 9). Although the amplitude and energy increased, the waveform remained essentially identical to the previous discharge waveforms (see Figures 5, 7, and 8). At this higher potential, however, a mild shock was felt by the individual when using the steel rod to discharge into the Pelligrini target.

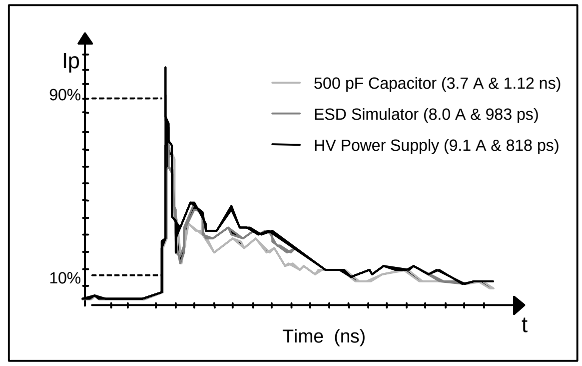

Figure 8: Discharge waveforms for a 2 kV charge, various charging sources

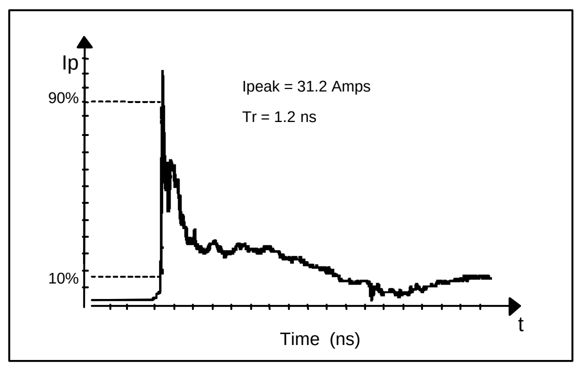

Figure 9: HBM discharge waveform, 8 kV charge

Capturing the ESD Event

To investigate the effect of parasitic inductance on the measurement of the actual human body event, the Pelligrini target was replaced with the CT-1 current transducer (1.5 GHz and 450 ohm) attached to the 50 ohm input of a 1 GHz preamplifier. Test subjects were charged to a 2 kV potential and discharged using the CT-1 probe (see Figure 10). The use of the CT-1 probe introduces approximately 90 nH of parasitic inductance into the ESD discharge path. This increased parasitic level resulted in the slower risetime, 15.55 ns as opposed to < 1 ns with the Pelligrini target, and dampened first peak amplitude, 3.12 Amps as opposed to 7 Amps with the Pelligrini target.

The importance of the procedure used to capture the ESD event cannot be overlooked. To highlight the effects of the measurement techniques used during this investigation and the resulting waveforms, several commercially available ESD test systems were characterized. These testers are used throughout the electronics industry to evaluate the protection circuitry of semiconductors or susceptibility level of a part to an ESD event. The majority of ESD test systems implement the HBM waveform as defined in MIL-STD 883C. Prior to subjecting a part to the test system ESD event, a waveform verification procedure is required. This is accomplished by capturing the ESD discharge waveform created by the test system and verifying that the waveform parameters (risetime, amplitude, etc.) are within the limits defined in the ESD standard being implemented.

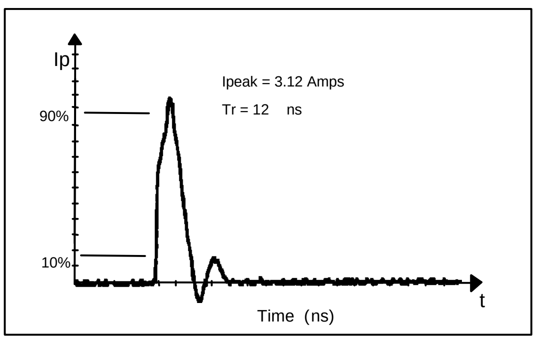

Figure 10: HBM discharge waveform (2 kV), CT-1 probe

The question is, "What does the waveform actually look like?" The answer to that question greatly depends upon the method used to capture the ESD waveform. Programming the ESD test system to a 2 kV potential level, the resulting discharge waveform was captured using the CT-1 probe (see Figure 11) and the Pelligrini target network (see Figure 12).

The waveform captured using the CT-1 probe, Figure 11, reveals the dampening effect of the probe's parasitic inductance. This particular measurement procedure, which is identical to the waveform verification procedure defined in MIL-STD 883C, resulted in the measured waveform parameters falling within the required limits of < 10 ns risetime and 1.33 +/- 10% first peak amplitude.

The waveform captured using the Pelligrini target network, Figure 12, resembles the "shape" of the ESD waveforms shown in Figures 5, 7, and 8 (although it does not show the same first peak current levels). Because the Pelligrini target network has a lower parasitic inductance, the measured risetime and first peak amplitude (3.2 ns and 3.3 Amps respectively) far exceed the waveform parameter limits defined in MIL-STD 833C.

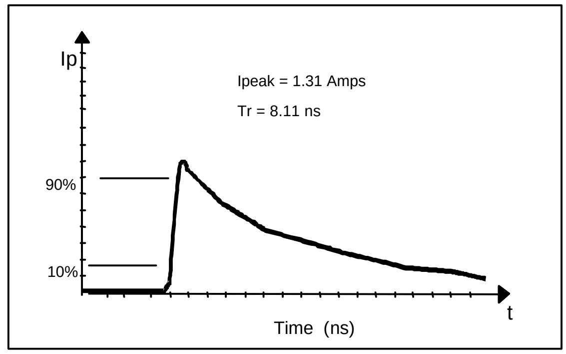

Figure 11: Test system ESD waveform (2 kV), CT-1 probe

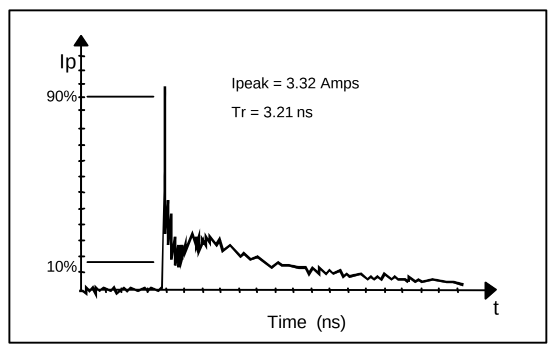

Figure 12: Test system ESD waveform (2 kV), Pelligrini network

While the same ESD test system produced both of the ESD waveforms shown in Figures 11 and 12, the procedure used to capture those waveforms revealed two different ESD events. Due to these observed differences, the question now becomes, "Which waveform verification procedure is correct?" These findings suggest the very real possibility that two (2) ESD test systems appearing to be equivalent using the MIL-STD 883C waveform measurement procedure may be significantly different when measured with the Pellegrini target. Due to time constraints, these questions could not be addressed in this study.

Further investigation in necessary, however, to establish an ESD specification and waveform verification procedure that represents the "real world".

Conclusion

This work was not intended to be an all inclusive study answering the questions which arise as you become involved in ESD, but was intended to stimulate interest in additional work toward answering several basis questions. This evaluation has shown that the true human body ESD waveform is significantly different from that specified in MIL-STD 883C, but is this difference important? Will it result in significantly different failure characteristics and thresholds in semiconductors tested with a fast risetime, high energy waveform similar to the true HBM waveform?

This work also suggests that a significantly different ESD waveform may exist; one that is dependent on the measurement method. This could be important when verifying whether two different test systems will result in identical ESD sensitivity level results. Additional work is required to established the appropriate test method and waveform verification procedure.

The testing performed with test subjects of widely varying body sizes and shapes demonstrated that while size is not the significant factor in determining the first peak power that will be observed in a human body ESD event, skin conductivity, body chemistry, or some other factor may be of primary importance.

We feel this evaluation and many other studies involving HBM ESD strongly suggest that some present ESD test requirements should be revised/updated to reflect what appears to be a new and significantly more correct definition of the HBM ESD waveform.

References

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