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# Correlation of component human body model and charged device model qualification levels with electrical failures in electronics assembly

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ABSTRACT

Electrostatic discharge sensitivity of integrated circuits is compared with electrical failure levels in electronics assembly. Electrical components with a low electrostatic discharge withstand voltage would be expected to have more electrical failures than more robust components. However, the analysis based on 47 products, 14 facilities, and 6 billion integrated circuits show no correlation between electrical failures and electrostatic discharge sensitivity of components. This was found when the withstand voltage of the components is equal or higher than 100 V human body model and 200 V charged device model.



## 1. Introduction

Electrostatic discharge (ESD) protection in electronics handling based on ESD control programs is established according to the standards IEC61340-5-1 and ANSI/ESD S20.20-2014 [1,2]. A purpose of the program is to establish an electrostatic protected area (EPA) that is able to prevent ESD-sensitive electronics (ESDS) to experience discharges above a 100 V human body model (HBM) and 200 V charged device model (CDM) [3,4]. When more sensitive devices are handled, additional control elements or limits may be required. It is also estimated that ESD sensitivity of components decreases due to the faster data connections and smaller silicon level geometries [5,3,6].

The component HBM and CDM withstand voltages have been compared with ESD risks, field failure levels, and system-level ESD immunity in several publications, including white papers from the Industry Council on ESD target levels [5–12]. The *White Paper I* compared system-level field failure rates to the single component HBM withstand voltages [5]. The data consisted of field failure returns for 21 billion devices with the HBM sensitivity of more than 500 V and shows no correlation between the HBM sensitivity and field returns. A similar study was carried out for the CDM withstand voltage data in the *White Paper II* [6]. This document presents statistics for 9.5 billion components and shows no correlation between field returns and the CDM sensitivity when the CDM withstand voltage is between 100 V and 2 kV.

There is less information available on how the HBM and CDM withstand voltage correlates with a manufacturing failure rate (MFR). The MFR is typically expressed as failing parts per million (*ppm*), and there can be its own *ppm* measures for different failure types, such as the *ppm* for electrical failures. Basically, an EPA should be able to prevent ESD events leading to electrical failures, but ESD failures can still exist in EPA and failure analysis with field returns have revealed EOS/ESD damaged components [7–13]. In addition, electrical components with a low HBM and CDM withstand voltage would be expected to have, in principle, more electrical failures, often reported as electrical overstress (EOS) damages, than more robust components [11–13]. Here, the coverage and completeness of an ESD control program should also affect the MFR. Facilities not fulfilling all the control program targets should, in principle, have more electrical defects due to ESD.

The *White Paper I* proposes that an EPA having basic ESD control methods should be able to handle components with an ESD sensitivity of more than 500 V HBM [5,3]. Similarly, the *White Paper II* proposes that a basic ESD control program can protect

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components with more than 250 V CDM sensitivity [6,4]. More sensitive devices would need more detailed control programs with equipment ground connection, charging, and discharge control. Especially, when the CDM withstand voltage is less than 125 V a specific audit is needed to find root causes of ESD risks and to control those by process specific control measures [6].

In this study, the component HBM and CDM withstand voltage information is compared with electrical failure levels in an electronics assembly. In addition, ESD control program assessment results are compared with the electrical failure levels in those facilities in which the *ppm* values have been collected. Electrical failures can originate via several reasons; therefore, electrical failures due to ESD events are analyzed with risk estimation methods. The main purpose of these analysis is to evaluate how the HBM and CDM withstand voltage information reflects the real electrical failure levels and how the withstand voltage information can be used to optimize ESD control programs in an electronics assembly environment.

MFR data collection is presented in Section 2, results and risk assessment methods are presented in Section 3, the discussion is in Section 4 and a conclusion is given in Section 5.

## 2. Methods

### 2.1. Electrical failure reporting

To compare MFR values with the CDM and HBM withstand voltages, a high number of products and different components need to be analyzed. A component failure rate can be close to zero *ppm* when all the electronic manufacturing processes are stable, and it may require even millions of components to be assembled and tested in order to obtain statistically reliable data for failure analysis. In addition, a change in the failure rate may come from several sources, as there is always some normal process and component quality fluctuation affecting the MFR. This increases uncertainties with failure source analysis.

Electrical components are tested in the electronics assembly when the assembled and soldered printed circuit board (PCB) is ready for electrical tests. Especially, a reflow process can stress components due to a high thermal profile. This may initiate delamination damages and cracks on silicon or package layers, and the failure symptom of these can be reported as an electrical failure [14]. However, most of these failures can be classified as manufacturing process related with basic failure analysis. In addition, EOS failures can occur during PCB testing [12,14,15]. There can be several testing, programming, and qualification phases during final assembly and packaging phases. Here, the product or assembly is connected to test equipment via pogo pins or an interface connector is used to power and measure product functionality [16].

Test data need to be highly detailed to identify the real failed component on a PCB. The test data may have specific phases identifying different system functionalities run by IC components under investigation. One common test interface is the on-chip test access ports based on a joint test action group (JTAG) used to read registers and logic state of the ICs [16]. This can be used to filter electrical failures out of other failure signatures and give component-specific failure data. An in-circuit tester can be used to track failed components even without built-in test features or active circuits. A separate system rework phase gives component-specific failure data, as more detailed measurements and software tools can be used to specify the exact failing component. However, most electrically failed components are not going through detailed failure analysis. Full failure analysis are typically done by component suppliers only when a significant number of similar failures occur in electronics manufacturing or the component has a high-quality requirement. Failure analysis is also able to identify the type of failure but cannot always define a source of the failure in detail.

In this study, the IC is reported to have an electrical failure when a tester has measured a specific component parameter to be out of the accepted range and when a component replacement in a rework has restored system functionality. Other failure types are marked as process or handling-related and are not part of the statistics. Some of the reported electrical failures are also proved to originate from ESD events by component failure analysis and process risk assessments.

### 2.2. Source of data

The MFR data is based on 47 different products with a total manufacturing volume of about 150 million units between 2007 and 2015. The products were manufactured in 14 facilities having automated surface-mount assembly, manual and robot-based final assembly, testing, programming and final packaging operations. These facilities are located in Europe, Asia, and South and Central America. A total amount of different ICs handled during this period was about 6 billion. From these products, all ICs were used during a preselection phase to analyze MFR and ESD sensitivity data. Finally, 37 ICs were selected for detailed analysis based on the ESD sensitivity, availability of ESD sensitivity data, and reliability of the electrical failure reports. Most IC components with the 47 products had the ESD sensitivity equal to or more than 2 kV HBM and 500 V CDM.

Out of the 37 components, 13 were used in several products during the same period. In addition, one product could have one to six similar components on each PCB; thus, the total component count reported in this study is about 1.5 billion. Fifteen components out of 37 have the ESD sensitivity less than 500 V HBM and 500 V CDM. The most sensitive components have the HBM withstand voltage 100 V, and six components have CDM sensitivity equal or less than 250 V. These most sensitive components are RF devices directly connected to antennas with an operation frequency between 700 MHz and 6 GHz. However, the reported ESD sensitivity of an IC is set based on the most sensitive I/O pin [3,4]. Therefore, a component with, for example, a 1 kV HBM and 500 V CDM level may have only one or a few I/O pins with this level, and all the other pins or pin combinations are more robust.

The collected electrical failure data is an average of a daily, weekly, or monthly score. Daily or weekly data are used to evaluate sudden changes in the reported failure counts, and the monthly data are used to track generic trends with component quality. The monthly reports give statistically the most reliable results due to higher manufacturing volumes.

## 3. Results

### 3.1. Monthly electrical failure data versus ESD sensitivity

Component HBM and CDM withstand voltages are compared with average electrical failures in Fig. 1, where letters represent different IC components. The figure shows that most components have electrical failure values below 50 *ppm*, and only five out of 37 components have over 100 *ppm* values. The highest *ppm* values are with components *q* and *r* where the failure symptom is not ESD related, as the damages were related to software problems in a tester. In addition, the failure rate with components *s*, *t*, and *a* is not related to ESD damages but to other EOS events leading to thermal damages. These failures were caused by false power switching sequences and misaligned flex cable connectors. The long-term failure counts are the most important from the total failure cost point