ESD and Disturbance Cases in Electrostatic Protected Areas

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50 Words Abstract – Electrostatic protected area (EPA) can effectively prevent ESD failures from charged operators, work benches and tools. However, electrical disturbances and ESD events from other sources can still exist in well-built EPAs. In this paper failures found in electronic assembly environments are analyzed to improve coverage of ESD control programs.

I. Introduction

ESD Control Programs based on ANSI/ESD S20.20 and IEC 61340-5-1 standards have the main focus on administrative and technical requirements of ESD control program and can provide an efficient environment to minimize ESD risks [1]. The coverage of these programs can vary from mostly image and show, to a more technical oriented approach [2,3]. Both of these program types can be fully compliant with the ANSI/ESD S20.20 and IEC 61340-5-1 standards as there are many ways to implement a program.

ESD Control Programs should be built based on the required protection level. The level of optimal protection depends largely on the type of electrostatic discharge sensitive components (ESDS) and the way ESDS are handled. In a manual handling process a basic control program can prevent more or less all ESD event based failures. However, when the handling processes contain widely different electrical products, mechanical components with dielectrics, and automated processes, some of the possible discharge risk scenarios may not be fully covered. One of the challenges is to detect and define the optimal level of ESD control required in each case.

When all the basic electrostatic protected area (EPA) precautions such as grounding and dissipative packaging materials have been established, additional ESD protective actions and process optimization tasks can still be done to improve the process yield and efficiency [2,4,8]. This requires some knowledge of the possible ESD related risk scenarios.

In this paper we present some major ESD and Electromagnetic Interference (EMI) failure cases found in EPAs. Here a failure means that significant amount of products have suffered electrical damage or the process yield has decreased due to testing or programming defects. These cases have been found by the authors in electronics assembly environments in different companies over the last 10 years. All these cases have occurred in EPAs mostly meeting both ANSI and IEC standard requirements, and the analysis bases on 42 individual failure cases fulfilling the criteria to be used in this study.

The presented distribution of failure cases and failure sources represents mainly electronics assembly processes in industrial, commercial and medical electronics area. The companies have been mostly medium or large size. Different failure distribution data may be found for example in a small scale manufacturing, semiconductor, automotive or aviation electronics manufacturing processes, where the type of ESDS, construction and handling of ESDS can vary. In this study component assembly phases have been fully automatized and most of the mechanical assembly operations were done manually, but also fully automated processes are included. The cases are collected from manufacturing sites located in Europe, Asia and South America.

The main purpose of this paper is to analyze the type and reason of the observed failures and thereby produce information to further improve ESD control programs and electromagnetic compatibility (EMC) related risk prevention in an electronics assembly environment. We will first present statistical data of the major ESD and EMI related failure cases in Chapter II. The data is further analyzed in Chapter III. We will discuss and show example methods found useful to minimize the observed failure cases in Chapter IV, and results are summarized in Chapter V.

II. Failure case analysis

A. Source of failures

The failure cases are analyzed by using three categories; source, event type and victim. The first category explains possible sources for failures based on the following items: static E-fields, ESD, EMI, External Power Supply (EPS), and a High Voltage (HV) source. The observed failure sources with the percentage information of the total are presented in Figure 1.

EPS is understood in this study as an external electrical power source such as a battery or a charger. The source is categorized as EPS when the event has included for example excess DC/AC voltage or wrong polarity plugging of the power source. These events can be initiated by an ESD event or EMI pulses, and in this special case the failure event include both sources.

The largest failure group in Figure 1 is ESD, which has been categorized when a direct ESD between the victim device and another object has caused the failure event. E-field is the source for example when an electrostatic force cause failures. HV is selected when the voltage alone is the source of a failure. HV and EMI are categorized as the source when, for example, HV cable sparking generates EMI pulses and the radiated RF noise disturb equipment operation.

The list of possible sources considered here has not included charged humans, seats, tables or other similar basic controlled EPA items. These were already well under control in the EPAs where the data was collected. The authors experience is also that failure cases from these sources are extremely rare and random in well controlled EPAs. It is also challenging to separate these from other possible electrical failure sources due to the low rate of occurrence. On the other hand, this experience supports the view that EPAs built based on current standards can effectively prevent these kind of failures.

B. Type of failure events

The second category shows a statistical distribution of failure event types based on the commonly used models; Human Body Model (HBM), Charged Device Model (CDM), Machine Model (MM), Cable Discharge Event (CDE), Latch Up (LU), and Charged Board Event (CBE). These events involve an electrical contact with charge transfer occurring. In addition, we use two additional event types based on Electrostatic Attraction (ESA) and failures due to radiated RF noise marked with EMI. The type and share of failure events is presented in Figure 2.

HBM is a discharge event between a human hand and ESDS, and MM represents a discharge from a charged conductive large equipment or mechanism. CBE and CDE include discharges from a charged ESDS assembly and also discharges between charged mechanics/cables and the ESDS. CDM is an event occurring when a single integrated circuit (IC) component touches conductive material with a charge transfer. ESA events are related to material sticking on charged surfaces and malfunctions caused by electrostatic forces. In a LU case the failure event is related to the excess current and voltage from a power source. The last event type EMI is a narrow or wide spectrum signal coupling into equipment or the product itself. Here only transient high amplitude signals with high power density are counted, thus, continuous low amplitude RF noise is excluded.

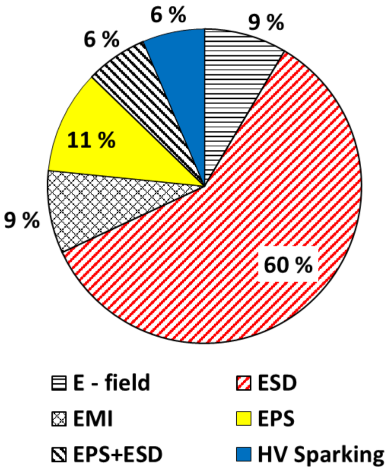

Figure 1: Observed failure sources.

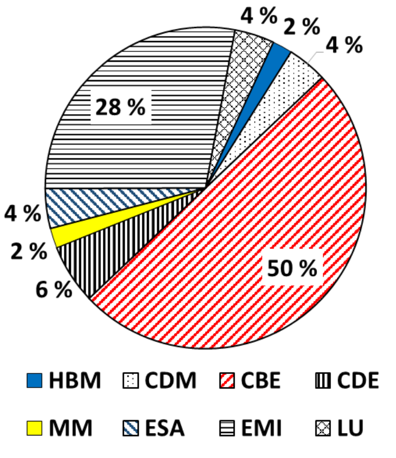

Figure 2: Event type leading to a failure.

C. Failing parts

The third category is the type of failing victim in EPA based on the first and second category. However, it is not always as straightforward to define a single victim for a failure. For example, RF noise can couple via a cable and through several components on a printed circuit board (PCB) before it reaches the IC that may finally produce the failure. Therefore, a specific IC has been selected to be the main victim only when failure analysis have proven the failure to exist inside the IC. In other cases the victim is selected based on the module where the failure was observed. A sensor and display module are selected as their own group as those can be typically tested separately, and a whole system is marked as the failing part when more detailed information is not available. In addition, electrical testers and equipment used in the process area are counted as one group.

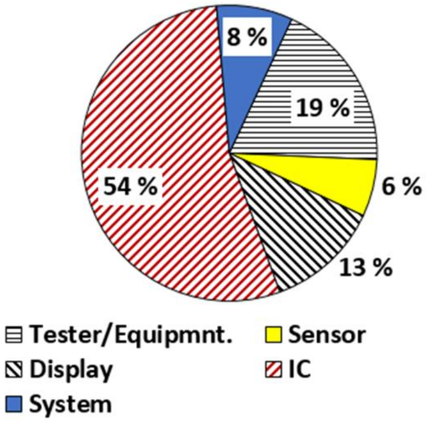

Figure 3: Failing items.

III. Failure case analysis

Figure 1 shows that more than half of the observed failure sources in EPA have been ESD events even though the EPA might be expected to prevent ESD from taking place. EMI and problems with power sources represent together about 25 % of the observed failure sources. Static E-fields and HV sources represent less than 15 % of the cases. This analysis suggests that a typical ESD control program may only partially cover E-field and ESD event detection, whereas HV sources and EMI detection can be easily overlooked. EPS sources can be challenging to detect as these depend strongly on the type of products and equipment used. In our experience the external power source has typically been a product tester, battery or programming equipment. Here the correct operation of software plays also a major role as the failure may occur only when the product is in a specific operation mode.

CBE is the most common failure event type in Figure 2. This is not surprising as subassemblies, PCBs and mechanical components are the most common parts handled in electronics assembly process. EMI events represent about one third of all the events leading to failures. This is consistent with the several testing phases typically required during electronics assembly, programming and qualification. Some of these testers are often built in-house and are not subject to EMC immunity or emission qualifications. The process area may also have a high variety of tools and equipment producing periodic EMI pulses or radiating RF noise to the close environment. Therefore, ESD or LU events are not the only source or event type leading to EMC related failures in an EPA.

The rest of the events in Figure 2 represents each less than 6 % of the total. However, HBM, CDM, MM, LU, CDE, and ESA together cover about 20 % of all the failure events. Therefore, it is important to evaluate these event types when optimizing EPA control.

An extremely high number of automated IC assembly operations has produced only very few CDM related failures. The data source used in this study includes billions of assembled components with less than 200 V CDM rating. The low number of CDM failures shows the low risk of ESD damage in the surface mount assembly processes used in most electronics assembly operations. In these processes ICs are kept inside tape and reel packages until the IC is picked up by a nozzle for assembly. CDM risk seems to be successfully kept low in the assembly phase by control of package materials, resistive solder paste on

PCB pads, and capacitive coupling between the IC and PCB prior to a component placement [7].

There is also one HBM event in Figure 2. In this case the source of the event was a charged system periodically discharging into a neutral person with mega Ohm range grounding. Thus, the discharge event was similar to a real life HBM, but the source of the failure was not a charged person.

Figure 3 shows that in about 50 % of the failure cases one specific IC in the product was found to be the main victim. The failure was due to a physical defect or a major electrical disturbance leading to a product failure. In addition, electrical testers and equipment have failed in about 20 % of the cases. This is once again related to the amount of EMI events and number of testing phases occurring in the EPAs.

Displays and other electrical sensors have failed in about 20 % of the cases. Many of the electrical systems have a display or sensors integrated, and these can be susceptible to both ESD and electrical disturbances due to EMI. In electronic assembly these components are still open and accessible for processing which increase ESD and EMI risks. Displays contain also large dielectric plastic or glass surfaces that can be easily charged for example by peeling off a temporary protection film. These surface charges may trigger ESD or ESA events leading to product failures.

The rest of the failures in Figure 3 are counted as system level. In this case the failure has been a complex combination of mechanics and electronics and it has been challenging to define a single failing component.

IV. Optimization of ESD control programs

According to the observed failure cases the greatest benefit for current ESD control programs in electronics assembly environment would come from enhanced CBE event control. In addition, expanding the basic ESD control on EMI pulse detection and mitigation would prevent major part of EMC related failures. This would not yet require expensive tools or specific competence, which is typically needed when RF signals or low amplitude RF noise is measured. Here a basic hand held EMI detector gives valuable information, and an oscilloscope with a dipole or loop antenna is able to measure the amplitude and position of the EMI pulses [5,6].

The challenge with CBE control is with the high variation of different assemblies and processes to cover. ESD sensitivity of assemblies is typically unknown and some of the assemblies may come from subcontractors without ESD sensitivity information. Products can also have varying process steps including product specific test phases. Here one way to optimize the control is to use a critical path principle, where detailed risk analysis is done only in those phases where assemblies are handled [2,3,4]. In addition, it is possible to measure the sensitivity of ESDS parts when the critical path, charging and handling methods are known in details [8,9].

CBE control requires to use additional measurement methods which are not fully documented. For example, charge analysis are not commonly part of measurement methods done at the manufacturing area. However, combining potential, charge and EMI measurements would enable better control over charged assemblies and other ESD risk locations.

EPS failure sources are most likely the most challenging to prevent and challenging to include in ESD control processes. EPS risks depends on the product type, test system and software used in the system. However, there are some generic rules to follow, such as to limit hot plugging of electronics, which should minimize for example LU damage risks. Naturally, this is not always possible if the system operation need to be tested in an electrical tester in a power on mode. Here a proper system EMC design would be the primary prevention method.

Three example cases are presented in detail to explain how EMI, CBE and EPS risks can be controlled in EPA. These failure cases are also part of the statistics presented in this paper.

A. Defects due to EMI

An electronic testing area had hand held pistol type compressed air assisted ionizers for dust removal and charge neutralization purposes. These ionizers were picked up and product surfaces were blown with ionized air for a couple of seconds. Operators were instructed to keep the ionizer steady, but they typically shook the tool during ionization. These AC type ionizers had two different type of cables in use. The cable included control signal lines, a high voltage wire and an air supply pipe in a single bundle with rubber outer casing.

During the usage the HV cable type *B* inside the bundle became physical damaged around the cable bending areas, as can be seen in Figure 4. The cable and ionizer still operated according to the specification, but the broken cables started to emit EMI pulses due to the sparking between the middle HV wire and a shield conductor. Some of the cables had cracks also along the center conductor. The generated RF noise radiated and coupled into product testers a few meters around the workbench and produced test failures. With some testers the testing failure rate was tens of percent's.

A Sanki EMI Locator tool was used to locate the source of RF noise. The detector was able to sense the broken cables a few meters distance, and by bringing the detector beside the cable, damage locations were seen from the LEDs informing the signal amplitude. The broken cables were tracked also by using an oscilloscope and antennas, and an example measured waveform is shown in Figure 5.

All the HV cables were changed to more robust type *A* and that solved the failure case.

Based on the EMI problems found the company integrated EMI control as a part of the ESD control program. EMI detection was carried out systematically close to the testing, programming and RF measurement equipment. This revealed several new significant EMI and a lot of low amplitude RF noise sources. It would have been difficult to remove all the noise sources. Therefore, to optimize the EMI mitigation new detailed measurement setups and control thresholds were defined. Based on the measurement data and risk analysis only the most relevant EMI sources were removed inside EPA.

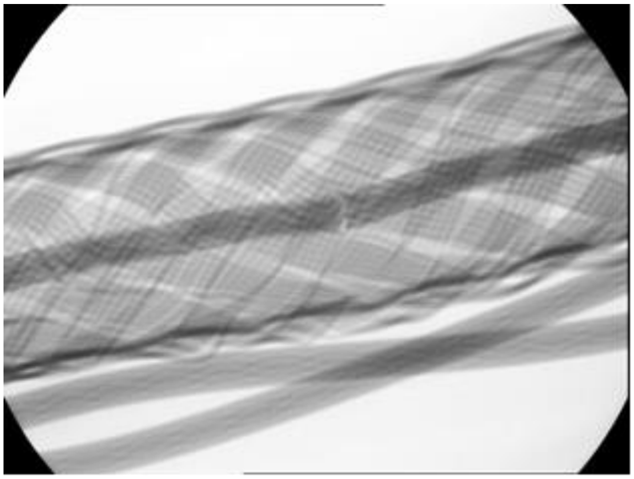

Figure 4: X-ray image of a broken high voltage cable.

B. CBE defect case

An electronic system had a small hard disk drive inside the enclosure. The hard disk was assembled with a rubber cushion material to protect the disk from excess accelerations and shaking. The disk and cushion material is shown in Figure 6.

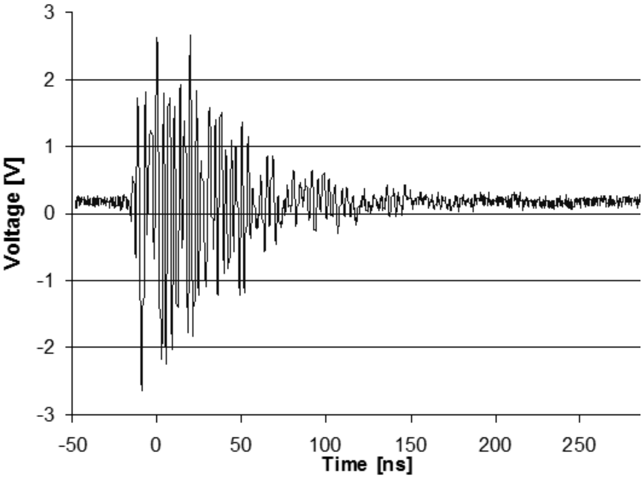

Figure 5: Measured EMI pulse with a monopole antenna.

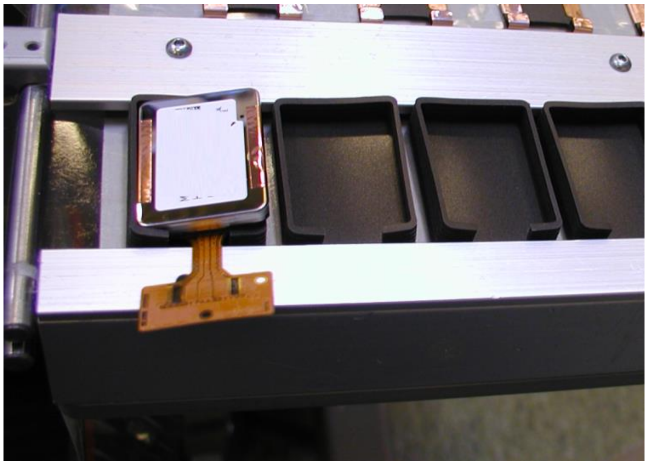

Figure 6: A hard disk and dielectric black color cushion.

Hard disks were found to have electrical failures in a final testing phase and the supplier of the disk reported electrical overstress or ESD damage with control electronics based on failure analysis. The hard disk had reasonably good ESD protection design and was able to withstand ESD up to 4 kV based on IEC61000-4-2 qualification. The enclosure of the disk was conductive and the handling area had all basic EPA precautions in place. However, the cushion material was made of dielectric rubber and got triboelectrically charged when the disk slid inside.

When the operator placed the disk inside the cushion material, he/she grounded the disk via hand and only less than 100 V surface potentials were found on the metallic enclosure of the disk. However, when the assembly was picked up from the feeder the capacitance of the assembly decreased, thus, increasing the static potential over 1 kV. In addition, the measured charge in metal parts of the disk was more than 10 nC. During the next assembly phases the assembly was poorly grounded due to the dielectric cushion material, and therefore, charges of the disk discharged into the main PCB when the flex connector was pressed in place. Random EMI pulses were also detected at the assembly location.

There was an additional ESD risk scenario, which is visible also in the Figure 6. The flex connector was able to touch on the metallic surface of the feeder during handling. This was prevented by adding a piece of dissipative material on the contact area.

The failure case was completely resolved by spraying semi-conductive liquid on the cushion surface prior to the assembly. That reduced charging phenomena until the system was fully assembled. Later on, the dielectric cushion material was replaced with a dissipative version.

In this failure case charge measurement was the primary method together with EMI detection to locate and analyze ESD risks. By using potential or E-field measurements alone the charging phenomena would have easily remained undetected. Therefore, a basic method to detect and analyze similar CBE risks is to use EMI, potential and charge measurements in parallel.

C. Latch up defect case

An electronic system was programmed via USB2 interface before it was packed for shipment. During a dry winter period programming equipment started to suffer electrical failure to a USB control card inside an industrial computer. Only one specific USB card model showed failures. In a short period of time tens of cards broke, but the products under programming were still fully functional.

The product had a plastic casing and that charged up to a few hundred volts when it was manually handled in the programming phase. This induced around 5 to 10 nC static charge on electronics inside the casing. When a worker plugged a USB cable into the product an ESD discharge went through the cable into the computer as shown in Figure 7. This discharge was relatively weak, but initiated a latch up phenomena in the USB card that led to damage to USB control circuits.

The process phase was measured with electrostatic field meters, EMI detectors and charge meters. There were systematic weak EMI pulses found when the USB cable was plugged in, but voltage or charge values were still well below set alarm limits.

The USB cable used had no extra ferrite bead EMC filtering. In addition, the ground shield of the USB wire was connected only in one end of the cable, thus, all the product charges discharged via the signal pins between the product and the USB card. The USB card had unknown EMC/ESD design and the primary corrective action was to improve EMC/ESD filtering with the data connection. The case was completely resolved by adding two low cost snap-op ferrite cores along the USB cable.

In this failure case the challenge was related to detection of possible ESD/EMC/EPS risks in the process, as only weak EMI pulses indicated problems in the process area. It showed also that even weak ESD or EMI events may trigger latch up or other fatal EPS events. In addition, the victim may not be always the ESDS, but another equipment used in the process area.

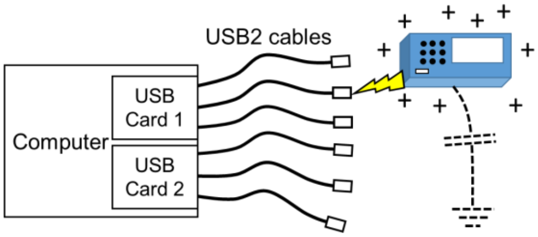

Figure 7: LU failure triggered by an ESD event.

V. Conclusions

ESD control programs are successfully used to prevent most ESD related failures. However, in this study we present statistics of failure cases found in an electronics assembly environment during the last 10 years. All these events have occurred in well controlled EPAs producing industrial, commercial and medical electronics. The purpose of this paper has been to demonstrate how to further improve ESD control programs to cover the most common types of events not currently addressed.

These failure cases are analyzed by categorizing them according to the failure source, event type and parts failing. As well as physical failures we include EMI related disturbances in the study, as these represent a major part of the cases found.

Current ESD control programs are not fully able to detect and prevent CBE and EMI related failures and disturbances. These represent about 70 % of the reported failure sources and around 80 % of the events leading to a product or system failure in electronics assembly environment. In addition to these, there are power source and ESA related challenges.

IC level failure has been proved in about 50 % of the defect cases. The second largest failing group are the electrical testers, programming tools and manufacturing equipment. The failure symptom is typically a system upset but hard failures were also seen.

Only a very few MM, HBM and CDE related events have been observed in this study. This is also related to the type of industry the data has been collected. Most of the products in this study have been computers, consumer electronics and medical systems. Therefore, EPAs with for example automotive electronics manufacturing, semiconductor or back-end processes may have a different failure distribution.

In conclusion, improving CBE and EMI control would be most likely to bring the most benefit for current ESD control programs used in electronics assembly. Here additional measurement methods based on EMI detection and charge measurement are required.

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