ESD Process Capability Assessment (EPCA)

A Technical Report

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ASCC AND SH&A

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1 Scope

This technical report provides an approach to determine the level of protection provided by the installed electrostatic discharge (ESD) controls in a process where unprotected ESD sensitive devices (ESDS) are handled.

The process applies to Human Body Model (HBM), Machine Model (MM), Charged Device Model (CDM) and other discharge waveforms that are not specifically identified based on waveform shape. These unidentified discharges are called "Hybrids" which may be combinations of two or more of the traditional discharge models or totally different from any of the well known waveforms.

This technique has been used to evaluate a large number of processes with widely varying ESD Models and device sensitivities.

2 Normative References

ANSI/ESD S20.20- For the Development of an Electrostatic Discharge Control Program for - Protection of Electrical and Electronic Parts, Assemblies and Equipment

ANSI/ESD STM 5.2 – Electrostatic Discharge Sensitivity Testing - Machine Model (MM) - Component Level

ANSI/ESD S 5.3.1 – Electrostatic Discharge Sensitivity Testing - Charged Device Model (CDM) - Component Level

ANSI/ESDA/JEDEC JS-001 – ESDA/JEDEC Joint Standard for Electrostatic Discharge Sensitivity Testing – Human Body Model (HBM) – Component Level

ANSI/ESD STM 97.2 - Floor Materials and Footwear – Voltage Measurement in Combination with a Person

IEC 61340-5- - Part 5-1: Protection of electronic devices from electrostatic phenomena- General requirements

3 Personnel Safety

The procedures and equipment described in this document may expose personnel to hazardous electrical conditions. Users of this document are responsible for selecting equipment that complies with applicable laws, regulatory codes, and both external and internal policy. Users are cautioned that this document cannot replace or supersede any requirements for personnel safety.

Ground fault circuit interrupters (GFCI) and other safety protection should be considered wherever personnel might come into contact with electrical sources.

Electrical hazard reduction practices should be exercised and proper grounding instructions for equipment should be followed.

4 Overview – ESD Process Capability Assessment (EPCA)

ESD Process Capability Assessment (EPCA) is a methodology that can be used to better understand the potential sources of electrostatic charging within a given process and the resulting types of ESD events (discharges) that may occur because of the charging that has taken place. It is important to understand both of these parameters when performing such an analysis.

ESD Process Capability Assessment (EPCA) will:

a) Identify the source/cause of charging within a process
b) Determine the ESD susceptibility model involved if the charge results in an ESD event

Once these two items have been clearly identified in a process it is possible to determine the level of protection provided by the process. If the ESD sensitivity for the devices being handled are known then the user of this technical report can determine if the process is capable of safely handling the parts.

EPCA is composed of the following steps:

a) Determination or estimation of the ESD sensitivity of the devices being handled.
b) Defining the process critical path
c) Identifying all possible charging and discharging points in the critical path.
d) Making EPCA measurements
e) Comparing the results to the sensitivity of the devices being handled as determined in step A.
f) Modifying the process to reduce or eliminate the charging of the ESDS or controlling the resulting discharge.

4.1 Determine device ESD sensitivity

Standards writing organizations such as JEDEC (Solid State Technology Association) and the ESD Association (ESDA) have developed test procedures to determine the ESD sensitivity of devices to various ESD waveforms. The tests are used, in varying degrees, by most semiconductor manufacturers to qualify the devices that they produce. The most well known models are:

- The Human Body Model (HBM) is meant to simulate discharges from people to ESD sensitive devices where at least one device pin is grounded.

- The Machine Model (MM) was developed to subject devices to discharges from charged conductors. Again, at least one device pin is grounded. It should be noted that MM qualification testing often provides the same information that is obtained from HBM testing except that the voltage failure level is much lower than HBM. This is one reason why organizations such as JEDEC and the ESDA do not feel that MM testing is required when **qualifying** products.

- The Charged Device Model (CDM) tests the susceptibility of devices to discharges from the device itself to other conductors. In this case the device is charged by inducing a charge onto the device from a charged metal plate located underneath the device and subsequently discharging the device with a grounded test pin

If all ESDS were tested to each of the above models, the user of these devices would have the information necessary to assess the process and determine if the devices were at risk.
Unfortunately, the semiconductor manufacturers do not test to each of the above models making it difficult for ESDS users to get a thorough understanding of the device sensitivity. At the same time it is not practical for the users of ESDS to test each of the devices that they use due to the high costs involved.

One approach that is used by many users of ESDS is to make a worst case assumption about the ESD sensitivity of the devices being handled. This information can be obtained from:

- Information about the known ESD sensitivity of devices currently being handled
- Published standards
- Documents published by the Industry ESD Council, JEDEC or the ESD Association
- Company projections about the ESD sensitivity of devices that will be used in future products

As an example, one EMS (electronic manufacturing services) company set up their ESD program using the lowest projected limits for HBM, CDM and MM based on the ESD Association's Roadmap for semiconductors. At that time the ESD program was established to protect devices that had:

- A HBM sensitivity of 100 volts or higher
- A MM sensitivity of 10 volts or higher
- A CDM sensitivity of 50 volts or higher

Customers were made aware that if their future new product introductions contained devices that were more sensitive than these values that it was their responsibility to notify the EMS company. Once notified that a more sensitive device was going to be introduced into their process the EMS company could perform a process capability assessment to determine whether or not the installed controls were adequate.

The following sections will give some additional information about the major ESD sensitivity models.

4.1.1 Human Body Model (HBM)

4.1.1.1 Background

This model is used by device manufacturers to determine the susceptibility of integrated circuits to simulated discharges from people. The human body model waveform, which is based on a typical person's resistance and capacitance, is similar no matter which industry test standard is used. In the HBM test circuit a 100 pF capacitor is charged to a known voltage and then discharged through a 1500 Ohm resistor into the device. At least one of the device pins is connected to ground. A typical HBM waveform generated by a tester is illustrated in Figure 1.

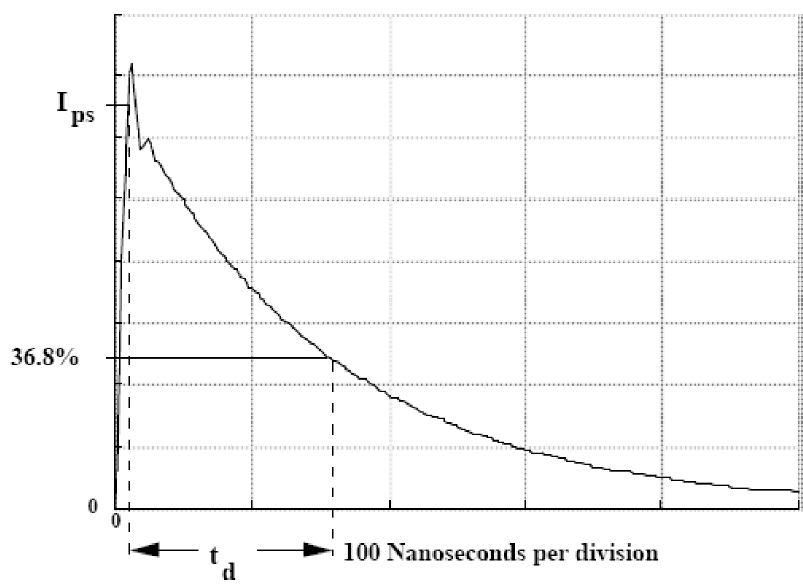
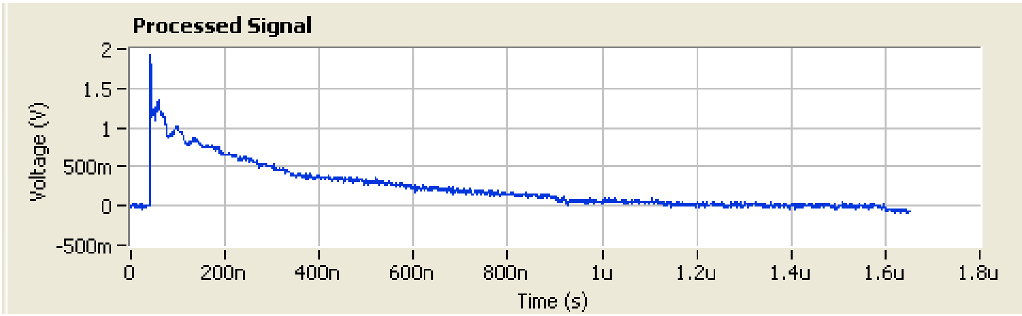


Figure 1: HBM Tester Waveform

Unfortunately, real life waveforms do not perfectly match those produced by an HBM test system. The waveforms will be slightly different for all personnel as a result of their individual capacitance and skin resistance. In addition, comparisons of the energy in the discharge from an HBM tester and a real person typically show that the energy from the HBM test system is usually higher.

Figure 2 represents a discharge from a person charged to 1,000 volts. The energy and charge were calculated by analyzing the discharge waveform. The energy and charge differences between the tester and the person are summarized in table 1.



Energy	**1.32E-05**
Charge	**7.52E-08**

Figure 2: Actual Discharge from a Person

Discharge Source (1,000 Volts)	Energy (uJ)	Charge (nC)
HBM Tester	50	100
Person	13	75

Table 1: Comparison of HBM Tester and Real World HBM

The actual discharge energy from a “real” person, in this example, is only 26% of the energy discharged from a Human Body Model tester. Does this mean that the real world walking voltage measurements of people, obtained using test methods such as ANSI/ESD STM 97.2, have no meaning or value? The answer to that question is “no”. If an ESD control program is established using actual walking voltage data with the assumption that **there is** a direct correlation between the walking test voltages and the HBM tester sensitivity values the program has an additional margin of safety that will ensure that HBM sensitive devices will not be damaged.

4.1.1.2 Controlling Charges on Personnel

Charges on people are controlled by connecting personnel to ground. There are typically two methods for grounding personnel – wrist straps and ESD footwear when used with a grounded ESD floor or grounded ESD mat.

Wrist strap systems consist of a wrist band that contacts the person’s skin. The band should be worn such that it completely contacts the skin and is not loose. A cord that is connected to ground is connected to the wrist band. When properly worn and connected to ground the voltage on the person should not exceed 10-15 volts.

A footwear/flooring system can also be used to ground personnel. In these situations industry standards such as ANSI/ESD S20.20 or IEC 61340-5-1 define the maximum resistance to ground for personnel. In addition, both of these standards require that the voltage on the person’s body be less than 100 volts. Greater care must be taken when selecting a footwear/flooring system. The user of footwear flooring systems must ensure that the footwear selected for use is compatible with the installed flooring. This is usually accomplished by performing a walking test using ANSI/ESD STM 97.2.

4.1.2 Machine Model (MM)

4.1.2.1 Background

This model is used by device manufacturers to determine the susceptibility of integrated circuits to simulated discharges from ungrounded conductors. The MM test circuit consists of a 200 pF capacitor charged to a known voltage and then discharged through a zero ohm resistance into an ESD sensitive device that has at least one lead grounded. A typical MM waveform generated by a commercially available tester is illustrated in Figure 3.

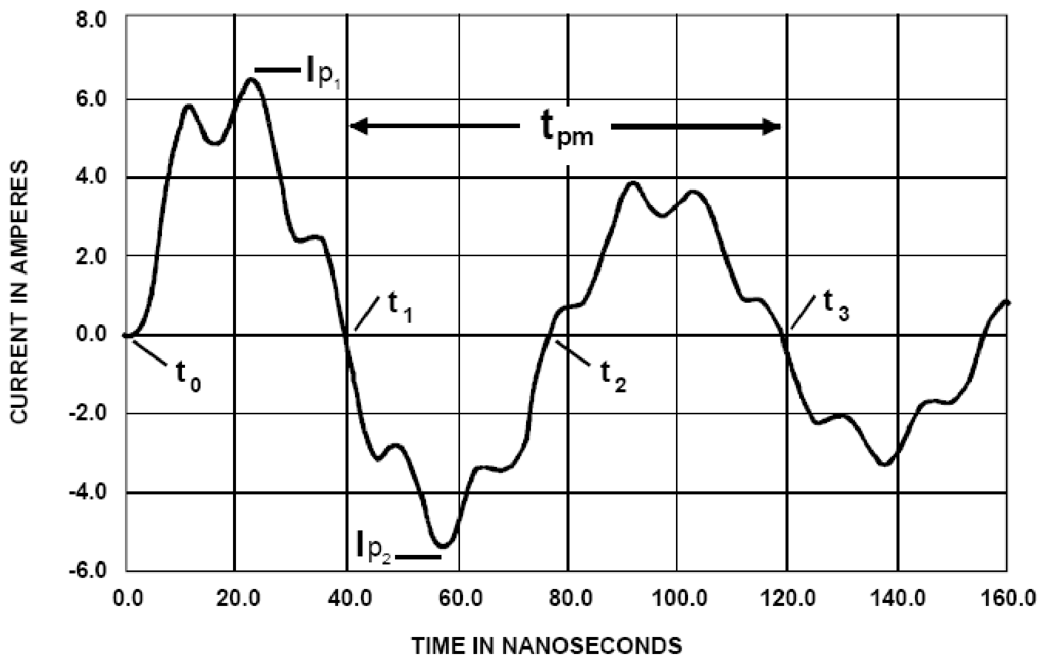


Figure 3: Machine Model Waveform

Machine Model ESD events are common place in processes where charged conductors are not grounded. Many believe that the charged item has to be a large, charged metal object. In fact MM ESD events can occur from conductors that are very small but have a high capacitance due to their proximity to ground.

It is suggested by many IC manufacturers that MM events do not happen in the real world. Figure 4 shows an example of a device damaging MM event in a printed circuit board manufacturing operation.

Many IC manufacturing companies do not perform MM testing as part of their qualification process. It is therefore often difficult for a user of these devices to get information about MM device sensitivity. If not available, the machine model sensitivity of a device can be roughly approximated by dividing the HBM sensitivity by a factor of between 10 and 30. As an example, if the ESD sensitive device had an HBM sensitivity of 1,000 volts the approximate MM sensitivity would be between 100 volts and 30 volts.

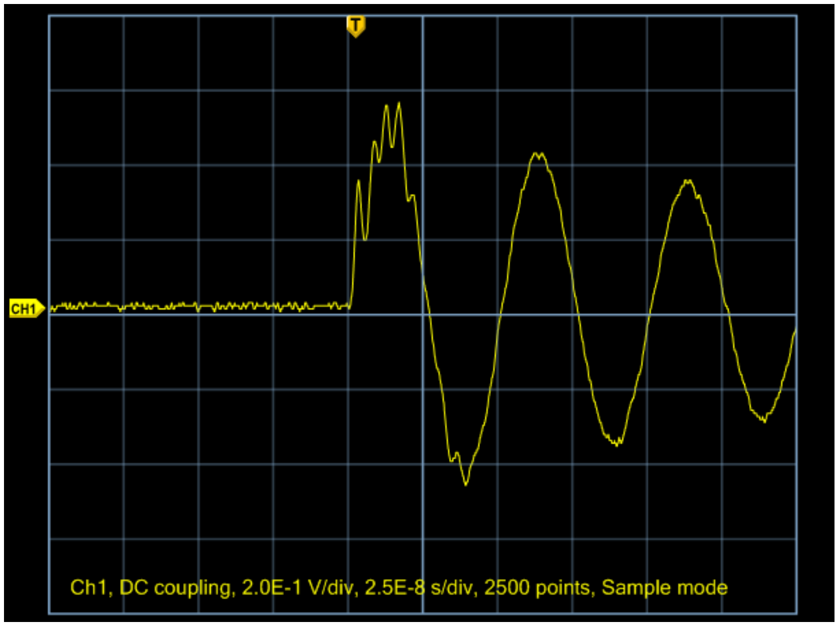


Figure 4: Real World Machine Model Discharge

4.1.2.2 Preventing MM Damage

Machine Model ESD damage can be prevented by ensuring that all conductors that come into contact with ESDS are connected to ground (preferred) or at a minimum cannot become charged.

This can be accomplished by measuring the resistance of the conductor to ground. Resistance values should be less than $1.0x10^9$ ohms. If the conductor cannot be grounded it should be checked to verify that it does not become charged in the process. This can be accomplished by using an electrostatic field meter or a contact volt meter.

4.1.3 Charged Device Model (CDM)

4.1.3.1 Background

Of all the ESD models, CDM is one of the most difficult to deal with although the basic concept is simple. The ESD sensitive device becomes charged in one of two ways, either through contact and separation with another material or surface or via induction. In both cases, the charged device discharges when brought into contact with a conductive surface. Figure 5 represents a typical CDM discharge based on commercially available testers.

As stated above, the charging of semiconductor devices can occur either by the direct charging of the device leads or through a process called induction. In order to fully characterize a handling process it is important to have an understanding of the process and how the parts move through it. The following sections will describe both scenarios.

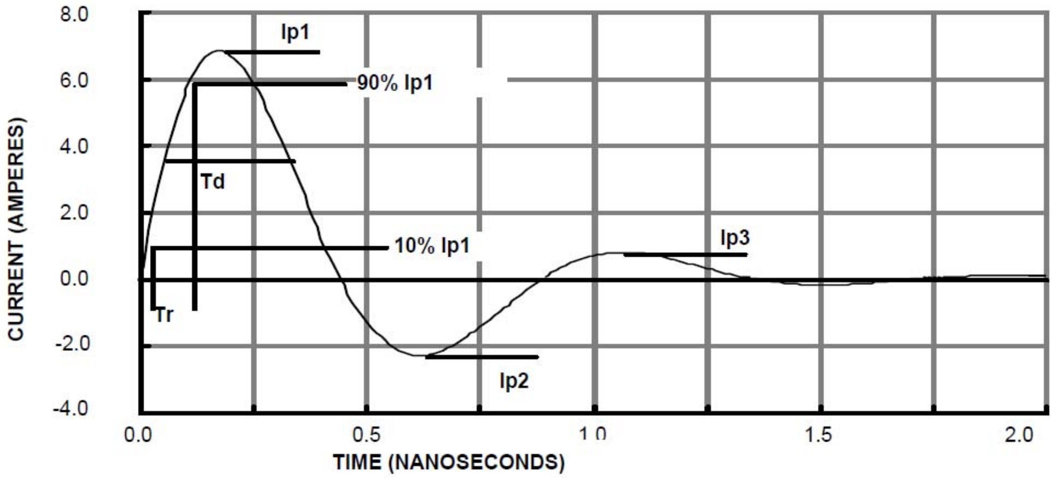


Figure 5: Typical CDM discharge

4.1.3.2 Direct charging (Triboelectric)

In this situation, the leads of the ESD sensitive device come into contact with a relatively high resistance surface. Upon separation of the device leads from this surface, electrons are exchanged between the device and the material. One item will pick up electrons while the other will lose electrons. This leaves the ESDS in either a positively or negatively charged state depending on the makeup of the material that the ESDS contact.

If the charged leads subsequently come into contact with another conductor that is at a different electrical potential, a CDM event will take place.

4.1.3.3 Charging from fields (Induction)

Virtually all processes require the use of insulative (high resistance) materials to some extent. Process required insulators can be easily charged through handling and the charge cannot be easily removed by grounding. A key result of insulator (or ungrounded conductor) charging is the electrostatic field that is associated with it. The electrostatic field extends some distance from the charged surface and can be measured using an electrostatic field meter.

If the charged item (insulator or ungrounded conductor) is brought into close proximity to an ESDS the field emanating from the charged surface of the item will create charge separation in nearby conductors including ESDS. If the ESDS is hard grounded while exposed to these fields a CDM event can occur. If the ESDS is charged to a voltage that is greater than its ESD withstand voltage the device could be damaged.

4.1.3.4 CDM Mitigation

For direct charging of ESDS, contact between the ESDS and highly charging surfaces should be minimized or avoided where possible. In some cases it might be possible to replace a highly charging surface with one that charges the ESDS to a lesser degree.

For situations where ESDS are charged when grounded in the presence of an electrostatic field the fields must be dealt with. This can be done in several ways:

- Separating ESDS from the charged insulator by a minimum of 30cm
- Add an air ionizer to all process steps where charged insulators exist.
- Treat the charged material with a topical anti-stat.

Note: Whichever method is chosen, the ultimate goal is to keep the voltage on the ESDS to a level that is less than its ESD CDM sensitivity.

4.1.4 Hybrid Discharges

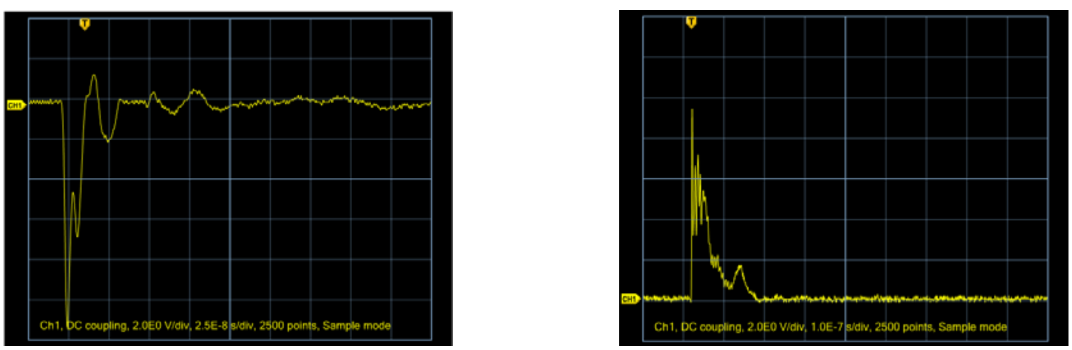
It has been noticed that in some situations the ESD discharge waveforms in a real manufacturing environment do not resemble any of the three models discussed above. Figures 6a and 6b show two examples of non-traditional ESD discharges. Figure 6A is a discharge from a charged signal cable while Figure 6b is an example of a discharge from a charged metal hand tool. The primary difference between the waveforms is the time duration and peak current.

Since semiconductor devices are not currently tested to these waveforms there is no data available about ESD thresholds when devices are exposed to these non-standard waveforms.

4.1.4.1 Hybrid Mitigation

Hybrid discharge sources must be viewed as potential sources of ESD damage. If the voltage on these discharge sources exceeds the minimum voltage for the standard models used to set up an ESD program then every attempt should be made to eliminate or reduce the voltage on these items.

As an example, an ESD control program is established to protect devices that have an ESD sensitivity equal to or greater than 100 volt HBM, 50 volts CDM and 25 volts MM. If the voltage on an item that contacts ESDS has a voltage of 25 volts or greater and the discharge waveform is classified as a “Hybrid” then action must be taken to reduce the voltage to less than 25 volts where possible.



Figures 6a and 6b: Hybrid Waveform Examples

4.2 Define the Critical Path

The critical path for any given process can be defined as all operations where ESD sensitive devices are handled for a given product. Each ESD sensitive process will have a defined starting and ending point.

Figure 7 represents an example of the critical path for a printed circuit board repair operation. The blue arrow indicates the start of the process where boards that have been returned from the field are loaded onto the conveyor by hand. The “red” arrows signify transport by wheeled carts between process steps.

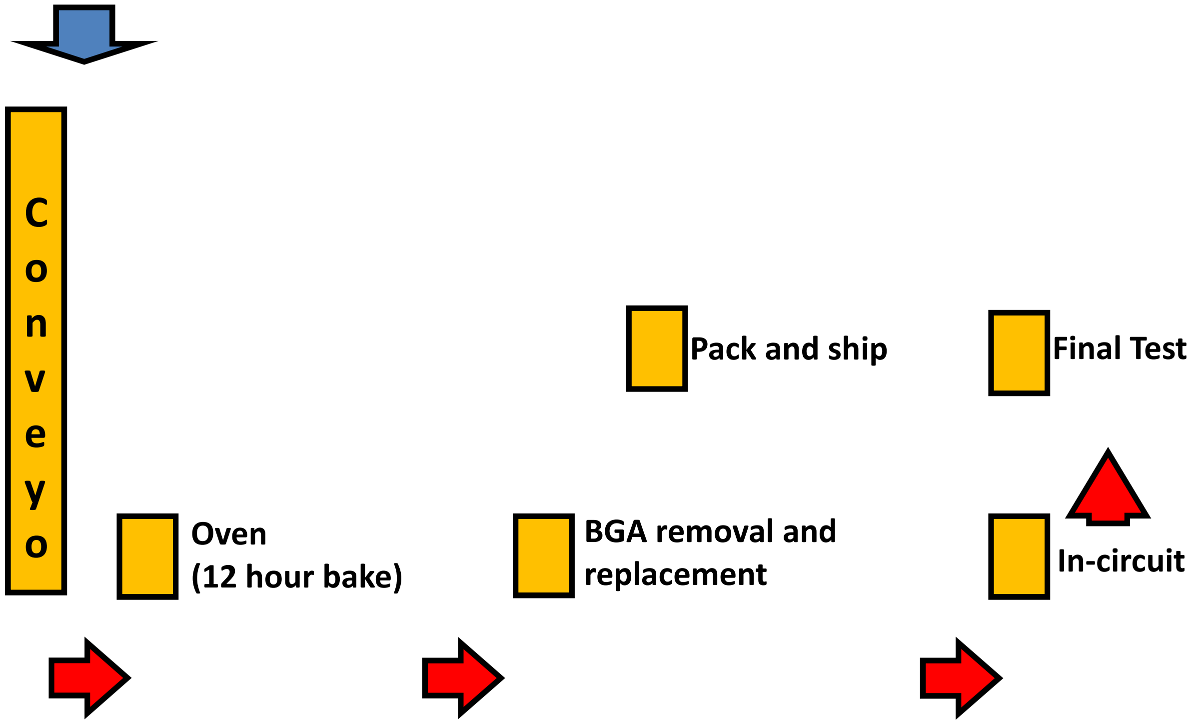


Figure 7: PCBA Repair Critical Path

4.3 Identifying Device Sensitivity and Critical Product Monitoring Location

Once the critical path has been mapped out the next step is to determine what point (or points) on the product requires monitoring as well as the ESD thresholds for the most sensitive device. For this particular product the customer identified a certain component that had the following ESD thresholds:

- Human Body Model (HBM) – 750 volts
- Charged Device Model (CDM) – 150 volts
- Machine Model (MM) – 50 volts

The customer specified the location on the board that was considered to be the most sensitive. This location was then used for all process measurements. *Note: In many cases the most sensitive location is not known. For these situations it is recommended that the board ground plane be used for voltage and discharge measurements.*

A detailed example of the analysis of the above process is provided in Section 6.

4.4 ESD Process Capability Analysis (EPCA) Measurements

4.4.1 Background

How are devices damaged from ESD? First electrical charge must be present. This charge can reside on the conductive leads of the device itself, on the insulating portions of the device, on charged items that are in close proximity to ESD sensitive devices, on charged conductors that come into contact with the ESDS or any combination of the above. ESD damage occurs when the ESD sensitive device comes into contact with a conductor that is at a different electrical potential that exceeds the damage threshold of the device.

When investigating a process we are concerned with the movement, charging and discharging of the ESD sensitive device of interest through the process.

ESDS can become charged through contact and separation with process items in the critical path, via induction when the ESDS is exposed to an electrostatic field or by exposure to an air ionizer that is not perfectly balanced.

Where are the measurements made? Experience has shown that the best locations for measurement are those locations where the product undergoes a transition. A transition is defined as a "passage from one form, state or place to another". For the purposes of ESD Process Capability Analysis, measurements occur at the beginning and end of each transition. "Transitions" include work on the ESDS as well as the transporting the product from one process step to another.

The following is an example of the transition points for the following process:

> *ESDS packaged in trays are placed into position at the rear of Surface Mount (SMT) equipment. The SMT placement head picks up the component and places it onto the printed circuit board.*

Transition points:

- ESDS is picked up from the tray (transition #1). The voltage on the ESDS is measured when sitting in the tray and immediately after pickup to determine whether or not the separation with the packaging is causing the ESDS to charge.

- ESDS is moved into position over the printed circuit board (transition #2). The voltage on the ESDS is measured before placement onto the printed circuit board.

- ESDS is measured after being placed onto the printed circuit board (transition #3)

Each transition point along the critical path will be evaluated to determine whether or not an item or the ESDS itself has become charged to a significant level. Through the use of this process it is possible to determine the source of the charge. Determining the source of the charging is a key parameter in understanding how devices can be damaged in a process. If the source of the charging is clearly understood, through measurement, then action can be taken to eliminate or reduce the charge.

If the source of the charging is not clearly understood it can result in process changes that are incorrect. Let's look at an actual example.

> *A facility has installed a static control floor and personnel are grounded via heel straps. ESDS that are packaged in trays are placed into position at the rear of the SMT equipment. The SMT placement head picks up the component and places it onto the printed circuit board. It was found that ESD events occurred (identified with an ESD event detector) when the ESDS made contact with the printed circuit board.*

In the above situation what is the cause of the charge and the resulting ESD event? It is easy to jump to the conclusion that the ESDS became charged after being picked up by the SMT placement nozzle. If that assumption were made then efforts would be made to somehow modify the placement equipment to prevent the charging. The ESD engineer may look at replacing the SMT nozzle with an ESD version if not already so equipped. They might also flood the placement area with air ionization in an attempt to reduce the charge.

In the above example, an analysis was conducted on the SMT process. It was discovered that the operator was charging the tray and the components to approximately 250 volts. When the tray was placed into position on the SMT equipment, the position designated for the trays was not grounded leaving the trays and the components in a charged state. When the ESDS were picked up from the tray they were still charged and it was this charge that was detected by the ESD event detector when the ESDS made contact with the board.

The solution was to place a grounded ESD mat on the surface of the SMT equipment. This allowed the charge, which developed due to the walking of the operator, to decay to ground prior to placement. Subsequent measurements showed that the leads of the ESDS were no longer charged and that discharges were no longer present after the trays were grounded.

4.4.2 Measuring Equipment

The following equipment is required to perform a process capability assessment.

a) Personnel (HBM)

- Charged plate monitor
- Hand held electrode & Shielded lead with shield connected to ground
- Recording Device
- Analysis software or computer spread sheet

b) All other process measurements

- Contact volt meter (CVM)
- Electrostatic Field Meter
- High Resistance Meter and Electrodes
- Storage Oscilloscope
- CT-1 or equivalent current probe
- Multi-meter

4.4.3 Determination of Body Voltage on Personnel (HBM)

Body voltage measurements can be made on personnel using an enhanced version of ANSI/ESD STM 97.2. The test procedure, as written, evaluates the voltage on personnel as they walk on a flooring surface while wearing the static control footwear used in the process. The test subject walks in a defined pattern on the sample flooring while holding an electrode that is connected to the voltage monitoring equipment (see Figure 8).

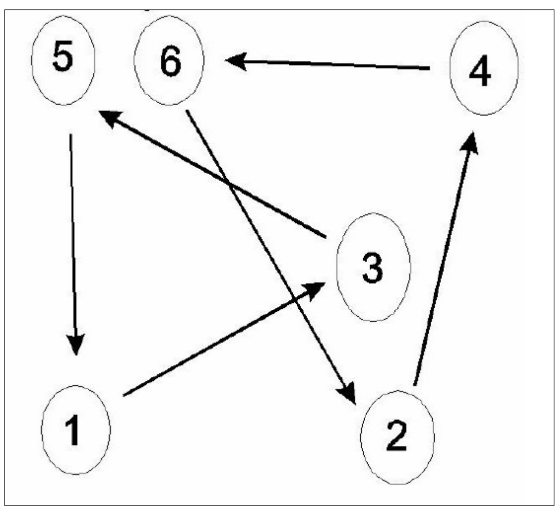


Figure 8: Walking Voltage Pattern

The resulting voltage-time graph (see example Figure 9, below) is then analyzed and the voltage levels are documented. ANSI/ESD STM 97.2 requires the calculation and reporting of the three highest peaks for each walking sequence. When Figure 9 is analyzed the three highest peaks are: 245, 243 and 231 volts.

ANSI/ESD S20.20-2007 requires that the three highest peaks must be less than 100 volts. The footwear flooring system from Figure 9 would not be considered to be compliant.

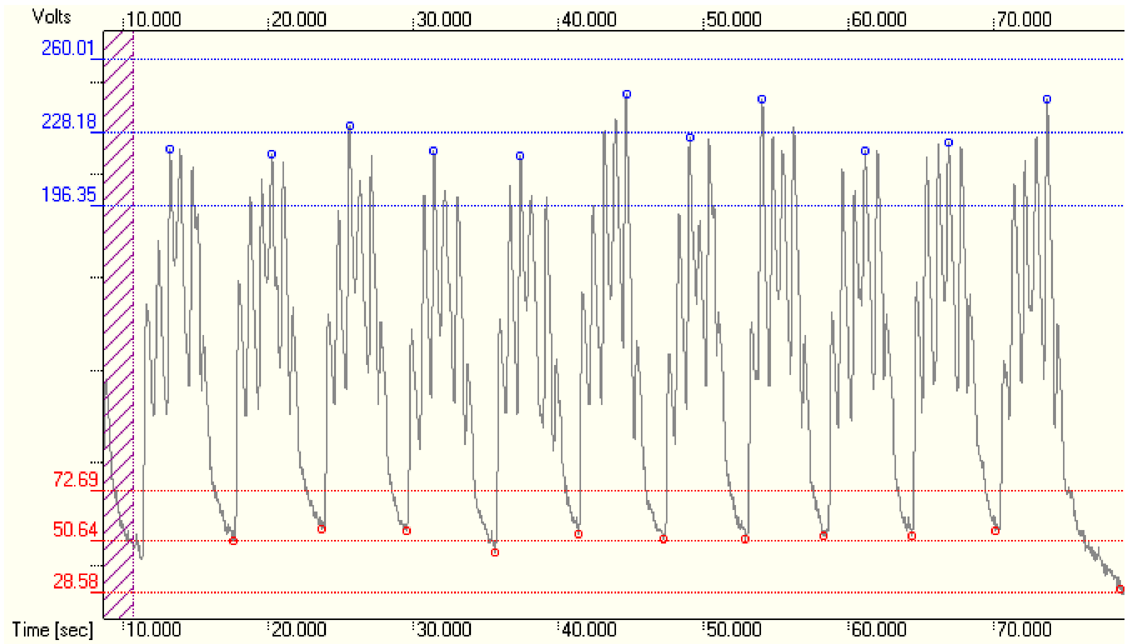


Figure 9: Recorded Walking Test

Experience has shown that it is difficult to make process capability statements based on walking test peak voltages alone. A better approach is to analyze the walking test voltages and to predict the probability that an operator will equal or exceed a certain body voltage.

Table 2 shows the results of the statistical analysis of the walking test data from Figure 9. This data shows that there is virtually a 100% certainty that this person will be at 191 volts or higher. It also shows that, for this person, there is a 50% probability that the individual will equal or exceed 228 volts. However, there is only a 0.13% that this person will equal or exceed 260 volts

Voltage [V]	196.35	206.96	217.57	228.18	238.79	249.40	260.01
Probability [%]	99.87	99.72	84.13	50.00	15.87	2.28	0.13

Table 2: Walking Test Analysis

When this type of analysis is performed on the walking test data it is possible to predict the performance of any given footwear flooring system. The testing should be repeated for a number of different personnel in order to understand variations in body mass etc. In addition, the testing should be done at the worst case relative humidity experienced by the facility (if possible) as this will result in the highest voltage levels.

If enough data is collected, using a sufficient number of people, it is possible to show the range for the worst case charging of the footwear/flooring system.

This analysis can be done with commercially available software or manually by exporting the data into a spreadsheet.

4.4.4 Non-Personnel - ESD Process Measurements

For the remainder of the ESD process it is necessary to make voltage measurements on the ESDS at each of the transition points discussed in section 5.4.1. This is accomplished by measuring the voltage on the ESDS (and conductive items that contact the ESDS) before and after each transition point using a contact volt meter. If the voltage on the item exceeds the "minimum" voltage of the most ESD sensitive model established for a process then the actual discharge model must be determined. As an example, assume that the ESD process was designed to protect devices that had the following ESD sensitivities:

- 100 Volts HBM
- 50 Volts CDM
- 25 volts MM

If the voltage measured on an item that contacts the ESDS (or the ESDS itself) equals or exceeds 25 volts (the lowest voltage threshold) then a current probe and a storage oscilloscope must be used to determine the ESD model involved. For the purposes of this example we will assume that the measured voltage was 40 volts.

The charged item is discharged at the point of transition (where the voltage was measured) and the waveform is reviewed and classified based on existing waveform models. It should be noted that is it not necessary to use an expensive, high speed oscilloscope for these measurements as we are not concerned with the peak current but merely the waveform shape. The contact volt meter gives us an accurate reading of the voltage on the item.

> Note: Can the ESDS be damaged when obtaining these discharge waveforms? The answer is "yes". This is why it is recommended that a non-functional product be artificially charged and discharged at transition points of concern if possible.

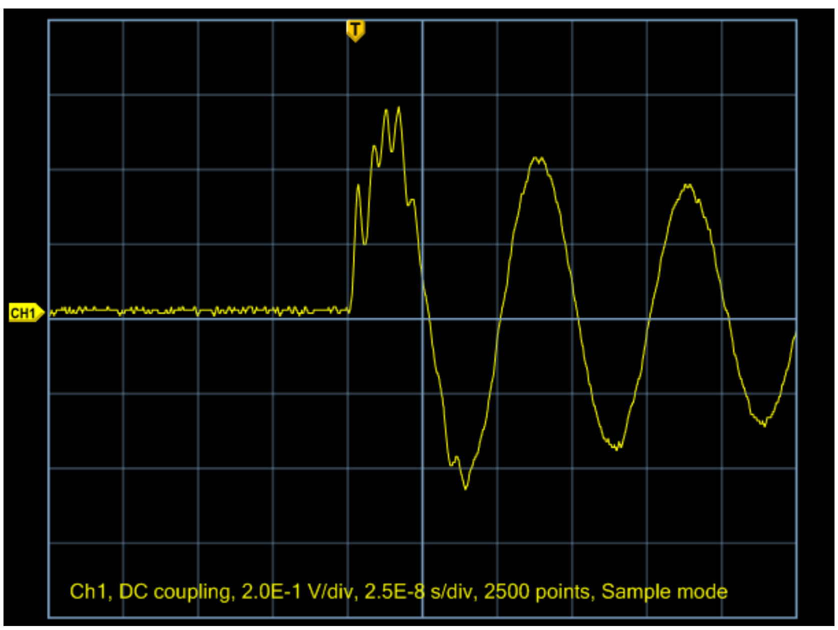


Figure 10: Machine Model Discharge at a Transition Point

Going back to our example, Figure 10 represents the discharge waveform at the transition point where 40 volts was measured on a charged conductor. Since the waveform is similar to a MM event this discharge waveform would be classified as a 40 volt MM discharge. Since this exceeds the 25 volt limit for MM, changes in the process will have to be made. However, if the discharge waveform had resembled a CDM event the CDM voltage threshold will not have been exceeded and therefore no process changes would be required.

It is important to make the discharge measurements at the location where the transition takes place. The reason is that the discharge waveform can be affected by the surrounding environment. Figure 11 shows a discharge from the same charged conductor. However the charged conductor was discharged away from the transition point and other grounded conductors that were located at the transition point. The discharge at the Figure 11 location is a CDM discharge.

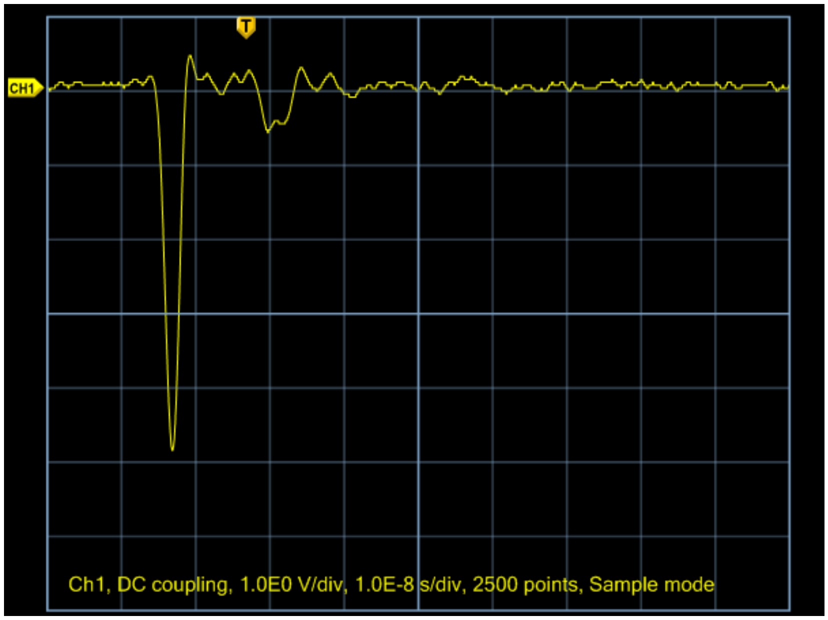


Figure 11: CDM Discharge outside of process

The measurement process is continued until the ESDS is no longer considered sensitive. This could occur once the ESD has been placed into a higher level assembly or when the ESDS is enclosed in ESD protective packaging. Section 6 at the end of this document provides an example of how process measurements are recorded in an actual process.

4.4.5 ESD Event Detectors

The primary tools for determining the capability of an ESD process, based on this technical report, are a contact voltmeter and a storage oscilloscope. However, there is another tool that is often recommended to ESD engineers to evaluate an ESD sensitive process. This tool, generically called an ESD Event Detector, can be used to detect ESD events.

One of the problems with some of these detectors is that they cannot differentiate between EMI and ESD. Noise in the environment from stepper motors, relays, solenoids, lightning and ESD is picked up by these detectors. Some units are designed to pick up only certain types of discharges such as CDM. However, unless it is known that CDM is the only process threat they generally cannot be used as a diagnostic tool by themselves.

These units do have a place in process analysis. Once a transition point has been identified as a point of discharge an event detector can be used to verify that ESD events are occurring. Figure 12 shows an ESD event detector that has been placed at the beginning of a re-flow oven. Process Analysis indicated that the printed circuit boards were charged after the component placement operation. The event detector confirmed that ESD events were occurring when boards charged earlier in the process were placed onto the re-flow conveyor.

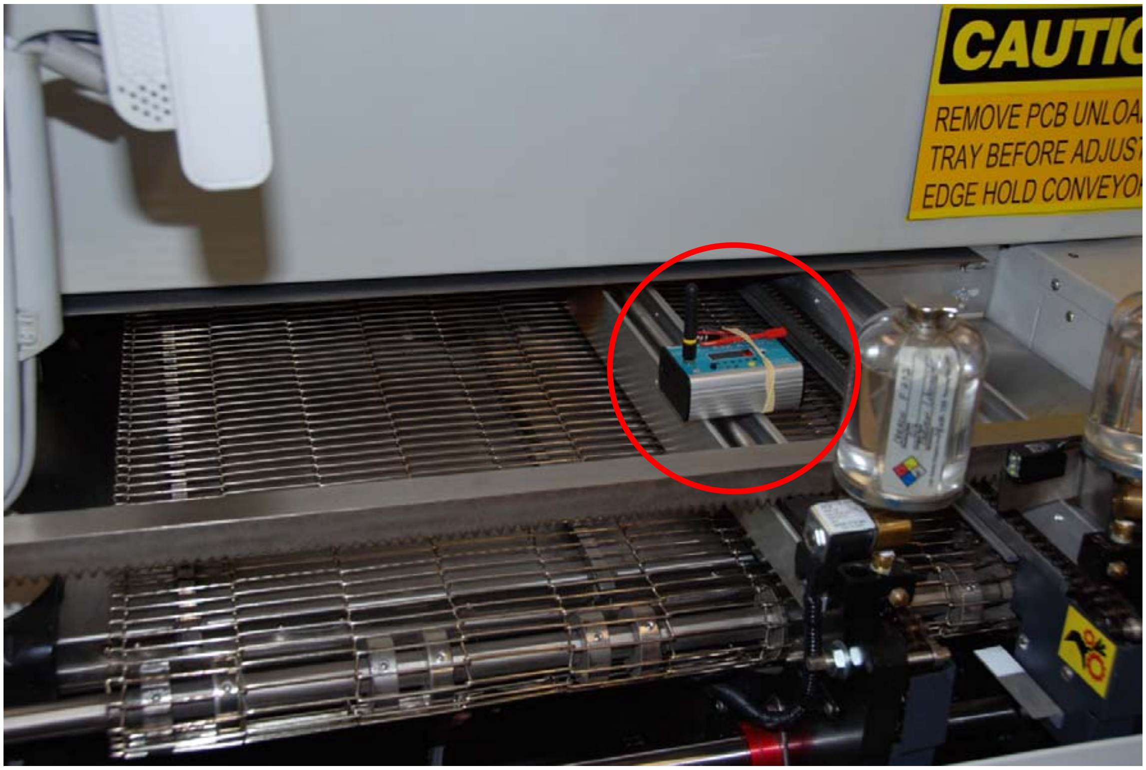


Figure 12: ESD Event Detector

Event detectors might also prove useful once a process has been analysed and all problems have been identified and corrected. Once the process has been stabilized, the detectors can then be placed at critical operations to ensure that damaging discharges have been eliminated on an on-going basis as long as the background noise in the environment does not cause false discharge readings.

5 ESD Process Capability Case Study

The following tables show the measurements taken during an actual ESD process capability analysis on a printed circuit board repair/upgrade operation as part of process qualification. The study was conducted at the request of a customer due to concerns with the use of a Ball Grid Array (BGA) device that was more ESD sensitive than its predecessor. The customer wanted assurances that the installed ESD process could safely handle a newly released BGA part. This part had the following ESD sensitivity thresholds:

- Human Body Model (HBM) – 750 volts
- Charged Device Model (CDM) – 150 volts
- Machine Model (MM) – 50 volts

Transi-tion ID	Description	Transition Beginning Voltage	Transition Ending Voltage	Charging Source	ESD Model	ESD Threshold Exceeded	Remarks
1	Remove boards from carton and load onto conveyor	<10	<10		N/A	No	
2	Fan / Heat sink removal	<10	<10		N/A	No	
3	PCBA Dust Removal	<10	60	Ionizer	N/A	No	Ionizer offset voltage exceeds industry & company limits. Must Correct Condition
4	BGA Clean	60	<10		CDM	No	Printed circuit board discharged through dissipative ESD matting at cleaning station– No threat to device but CDM discharges could have resulted if contact were first made with operator tools.
5	Placed on conveyor & moved to sorting	<10	<10		N/A	No	
6	Boards loaded onto transport carts	<10	60-80	Carts/ Personnel	MM	**Yes**	Oven carts not properly grounded. Personnel wearing heel straps had walking voltages of 139-180V leaving carts charged at ≈100V. MM discharge to some PCB's placed on cart.
7	Carts moved to oven	60-80	60-80	Carts/ personnel	N/A		
8	Boards removed from cart and placed onto metal oven shelf	60-80	<10	Carts/ personnel	CDM	No	Charged parts are removed from carts & placed onto metal oven shelves. ESD event recorded when board makes contact with grounded shelf. PCB discharge: CDM.
9	Board removed from oven and placed onto different (grounded) carts.	<10	<10		N/A		
10	Carts moved to BGA removal	<10	<10		N/A		
11	BGA removal	<10	<10		N/A		
12	Board cleaning	<10	40	Plastic Cover	CDM	No	Cleaning operation Microscope's Plastic cover inducing charge onto board during handling, then discharging through grounded operator tools.
13	Visual inspection	40	<10	Plastic Cover	N/A		Charge removed from board when placed onto dissipative ESD mat. No ESD events recorded at this operation.

Table 3: ESD Process Capability Transition Findings 1 - 13

Transi-tion ID	Description	Transition Beginning Voltage	Transition Ending Voltage	Charging Source	ESD Model	ESD Threshold Exceeded	Remarks
14	Paste deposition	<10	<10		N/A		
15	BGA replacement	<10	<10		N/A		
16	Selective re-flow	<10	<10		N/A		
17	Visual inspection	<10	<10		N/A		
18	Board X-Ray	<10	<10		N/A		
19	Load carts for movement to in-circuit test.	<10	<10		N/A		
20	Remove boards from carts and load into in-circuit tester.	<10	<10		N/A		
21	Plastic cover closed over board in-circuit test initiated.	<10	170-210	Plastic Cover of Tester	CDM	**Yes**	Charged plastic covers inducing charge onto board prior to test. Contact between board and equipment as test pins contact board results in CDM discharge. Discharges recorded using ESD event detector.
22	Boards removed from in-circuit tester and loaded onto carts for movement to Final Functional Test	170-210	<10	Plastic Cover of Tester	CDM	**Yes**	ESD events were recorded when the charged board was placed onto a grounded metal cart by the operator. This ESD event was caused by the charged covers.
23	Move cart to Final Functional Test	<10	<10		N/A		
24	Remove boards from cart to Final Test	<10	<10		N/A		
25	Final Test	<10	<10		N/A		
26	Pack and ship	<10			N/A		Last measurement is the voltage on the board before being inserted into ESD package.

Table 4: ESD Process Capability Transition Findings 14 - 26

The ESD process, as installed, was not adequate to protect the customer's ESD sensitive part, as summarized below.

ESD Model	Customer Requirement (Volts)	Initial Process Capability (Actual)
Human Body Model (HBM)	750	~ 200
Machine Model (MM)	50	~150
Charged Device Model (CDM)	150	~225

Table 5: ESD Process Capability Transition Findings - Summary

Note: although the HBM values for the process were far below the ESD sensitive device's HBM threshold it was personnel charging that resulted in the MM discharge recorded at transition 6.

The following process modifications were made based on the process analysis measurements:

- The ionizer was balanced to less than 20 volts.

- All personnel were required to wear approved ESD footwear. The temporary employees at the beginning of the process had been initially provided with heel straps as a cost saving measure. Heel straps did not meet Corporate ESD requirements for body voltage generation and should not have been used. Once the proper footwear was distributed the HBM capability for this process dropped to less than 50 volts.

- ESD wheels were added to the oven carts used at transition 6 which allowed them to be properly grounded through the installed ESD flooring. Once installed, the MM discharges at transition point 6 and the CDM discharges at transition point 8 were eliminated.

- The plastic covers at the in-circuit tester were initially coated with an anti-static chemical. This immediately eliminated the CDM events which were recorded with an ESD event detector. The permanent solution was to replace the plastic cover with a grounded static dissipative material.

Once all of the changes were made to the process, the measurements for the modified process steps were repeated. The final process capability limits for this process are:

ESD Model	Customer Requirement	Process Capability (Actual)
Human Body Model (HBM)	750	<50
Machine Model (MM)	50	<30
Charged Device Model (CDM)	150	<50

Table 6: ESD Process Capability Transition Performance after Corrections

6 Summary

The processes where ESD sensitive devices are handled vary dramatically and can range from simple to complex. What is important is to determine the level of ESD protection that a process provides. This can only be accomplished by measuring the entire process where ESDS are being handled. The following are some key points that have come out of our process analysis work:

1. The presence or absence of moisture (relative humidity) will have an impact on the charging levels that are measured in a process. Does this mean that RH control is required? No, however for processes where RH control is not present, it is critical to select and install ESD control products and materials that work at the lowest RH values that could occur in the process.

2. The selection of the ESD control items that are used plays a critical role.

    a. Do the materials actually meet the manufacturer’s published specification?
    b. Do these products and materials meet the technical limits in standards such as ANSI/ESD S20.20?
    c. If the ESDS are ultra sensitive are the limits in standards such as ANSI/ESD S20.20 good enough? Limits that are more stringent than those required by ANSI/ESD S20.20 or IEC 61340-5-1 may be required.

3. The type of ESD events that devices are exposed to is process dependent. It should never be assumed that one discharge model predominates. The only way to verify which model you are dealing with is to measure it with an oscilloscope.

4. Education is necessary in order to make effective process measurements.

5. In a well designed and implemented ESD program ESD events do not occur at each process step.

Reference

R. Gibson, S. Halperin, J. Kinnear, *“Process Capability and Transitional Analysis”,* EOS/ESD Symposium & Proceedings, Tucson Arizona, September 2008, ESD Association, Rome, NY

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While employed by different companies this innovative duo has worked together on behalf of the ESD industry and the Association for over 30 years. Both have:

- Served as senior officers and President of the ESDA
- Were instrumental in the ESDA’s long term strategic planning and implementation of Association activities
- Have been active in Symposium management, activities and paper presentations
- Received the Outstanding Contribution Award for their major contributions to the ESD industry
- Spearheaded the growth, domestic and international activities of ESDA Standards, Education, ANSI/ESD S20.20 Facility Certification, and Certified Program Manager committees
- Spent the majority of their professional careers in ESD control technology development
- Serve internationally as Certified Program Manager Instructors

Steve Halperin owns and operates Stephen Halperin & Associates, Limited (SH&A) and Prostat Corporation. SH&A specializes in ESD Advisory Services, Testing, Facility Evaluation and Training. Prostat designs and manufactures portable instruments for electrostatic evaluation and measurement of materials, ESD sensitive processes and environments. Steve is also a recipient of the Joel P. Weidendorf Memorial Award for his ESD standards development work, and “Best Paper” award in past Symposia.

Ron Gibson is the owner of Advanced Static Control Consulting which provides ESD Services to industry including: Consulting Services, Testing, Facility Evaluation, Program Design and Training. In addition to holding several officer positions at the ESD Association (ESDA), Ron was the ESDA Standards Committee Chair for over 10 years, is Canada’s chief delegate to the IEC TC 101 on Electrostatics and is a past General Chairman of the ESD Symposium.

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