

ELECTROSTATIC DISCHARGE (ESD) – SOURCES OF ELECTROSTATIC CHARGE IN A PRODUCTION LINE (SMT) – Measurements of Chargeability

Hartmut Berndt
B.E.STAT European ESD competence centre
Kesselsdorf, Germany
phone: (+49) 35204 203910
e-mail: hberndt@bestat-esd.com

Abstract— The number of failures caused by electrostatic discharges (ESD) has been increasing for some time now. So, it is necessary for everyone, who handles electrostatic sensitive devices (ESDS), to know the reasons of such failures. This presentation will give an overview about possible causes for ESD in a SMT production line.

I. INTRODUCTION

Particularly automated production lines have some processing steps, where electrostatic charges are increasingly generated. So far, one has been focused on the human being. This is controllable. Measurements in production lines show electrostatic charges at the following processing steps: application of soldering paste (printer), assembling (automated and manual pick and place), and labeling as well as optical and electrical tests (ICT). The electronic components are always assembled directly and without any covering on the PCBs. Thus, the wire bonding process leads to a damage of the electronic components. This process step is a very critical part in the production line. The electronic devices will be directly contacted with a metal needle.

The process steps, where the PCBs are covered with enclosures must be inspected either. Such enclosures are mostly made of isolating materials, like plastics. Thus, those can be electrostatic charged highly, while assembling.

All electronic components and assemblies are to be at risk of electrostatic discharges. Producers, suppliers, distributors and users have to realize the ESD control system during the completely manufacturing process, during the measurements as well as during the application. All active electronic components, beginning with simple diodes, transistors or complex inner circuits, require an external ESD control system. In the next step, SMD resistors and condensers, and prospectively NEMS and MEMS will be included in this danger category. Tests show, that these passive components can be damaged through electrostatic discharges.

The structures of electronic components become smaller. Already 5 volts of an electrostatic charge are enough to change the structures in small electronic components. The structures will achieve such small dimensions, so electrostatic charges can cause permanent damages. In the year 2030, the sizes of the electronic components will be less than 10 nm. Electrostatic charges of 0,1 nC and electrostatic fields of 10 V/cm will be enough then to damage ESDS permanently.

II. BASIC

In the last few years, many directions and worldwide standards for static control handling of electrostatic sensitive devices (ESDS) have been created. The basic principles for all steps are the safe (and slow) electrostatic discharge as well as the avoidance of electrostatic charge developments. These principles are necessary. They are included in all directions and standards. The international standards IEC 61340-5-1 (Draft 2016) and IEC 61340-5-2 (Draft 2017) contain these basic requirements for the protection of electronic devices and components against electrostatic discharges. Additionally, these standards obtain a program to prepare an ESD control system (ECS) in the electronic production line. The ESD control system conforms to the program of the American Standard ANSI/ESD S20.20-2014.

III. FAILURE MODELS (CDM, CBM, FICBM, HMM)

Different failure models are used for the analyses of humans and machines. The HBM (Human Body Model) is always used for the electrostatic charge of a person. Otherwise, the CDM (Charged Device Model) is applied for the charge analysis of machines or production lines. Nevertheless, both will not be sufficient in the future. New failure models like the CBM (Charged Board Model) or the FICBM (Field Induce Charged Board Model) become necessary. The CDM only considers a single electronic component; however, the CBM is applied to analyze the whole PWB.

Reflecting the following considerations, single failure models are caused:

- A person touches an electronic component and the stored electrostatic charges are transported from the person to the electronic component. These charges are grounded by the connection between the electronic component and the earth potential.
- An electronic component or an electronic device acts as capacitor plate and stores electrostatic charges. While contacting the earth potential, damages are caused by a discharge pulse.
- A charged object is in an electric field. A potential is generate over the Gateoxid or the pn-junction of an electronic component. Electrostatic charges are generated and discharges cause damages (break down).

Already known failure models:

- HBM (Human Body Model) - HMM (Human Metal Model)
- MM (Machine Model)
- CDM (Charged Device Model)

- FIM (Field Induced Model)

Charged Device Model (CDM)

The electronic component acts as a condenser. It gathers charges, such as caused while sliding through a magazine or while contacting another charged object. Additionally, electrostatic charges are generated by removing the electronic component from a conductive tray or a belt. Electrostatic charges are generally caused by taking an electronic component out of conductive material, because it is not equipped with a conductive enclosure. Thus, an electronic component is always electrostatically charged after every mechanical process, independent of its actual handling like the movement in a pick-and-place machine or another production line. However, just only a discharge damages the electronic component. The discharge can be realized directly or indirectly via further processes. It is just enough to bring the electronic component in the near of a dischargeable point or object. Therefore, an electrical or electrostatic field may already provoke such a discharge. Damages of pn-junction, dielectric and other components are caused by a discharge impulse and its discharge current, depending on the grounding via the enclosure or the chip.

An electronic component can store energies up to 100 μJ . However, at a very low contact resistance ($< \text{m}\Omega$) and a conduction inductivity of 10 nH, such energy, depending on the charge amount, can realize a direct or an indirect connection to the earth potential. An output per impulse of several 100 W to 1000 W is reached by an increase of the discharge current impulse of several ns. Such outputs are enough to change the component parameters considerably or to destroy the electronic component finally.

Charged Board Model (CBM)

The previous models HBM and CDM are not enough to describe ESD failures. There will be almost breakdowns caused by humans, but the most ESDs are moved in automatically handling equipment's. There is no direct influence of the human. The electronic components and assemblies charge themselves electrostatically. The capacity conditions of a PWB are absolutely different in comparison to humans. That is why one searched for a new model for some years because of starting with new conditions. One solution is the charged board model (CBM). Here the capacity proportions are very difficult. The value of the capacity is higher as the body of the person. The result is a bigger electrostatic charge on the board. We have a bigger energy at the discharge. This leads to the influence of ESDs and it damages the ESDs.

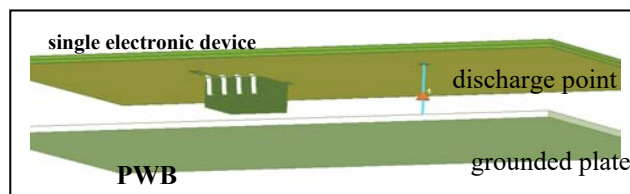


Figure 1. Typical CBM discharge

Field Induce Charged Board Model (FICBM)

A different model is the FICBM. The influence of the electrical field on PCBs has been neglected or has been thought that it is not important, until now. An electrical field is able to produce electrostatic charges on a PCB, like demonstrated. These electrostatic charges will be stored by the bigger capacity of the PCB or by the electronic components on it. The discharge process is not predictable. It can always happen, when the PCB is grounded or contacted. That is why the description of FICBM is not easy, but the effect is very important. Electrical fields can appear everywhere, where machines, motorized plants stand or where circuit processes are produced.

Human Metal Model (HMM)

A new or other failure model is the HMM (Human Metal Model). People held a crew driver or a metal tweezers in the hand and contact a pin of an IC. The charge flows about the IC to ground. The device will be damaged. The generator for this model is a HBM Gun analogical to the discharge after IEC 61000-4-2 Device Testing. The failure model HMM is an alternate model for a real test method for stressing pins of electronic components such as integrated circuits, single transistors or diodes, other elements. The generator for this model is a HBM Gun analogical to the discharge after IEC 61000-4-2 "Device Testing". The failure model HMM is an alternate model for a real test method for stressing pins of electronic components such as integrated circuits, single transistors or diodes, other elements. In the figure 2 is the test setup for HMM about a single IC.

The protection elements that will be directly connected to an external port of a system and may be subjected to a system level ESD stress, or ESD stress waveform. It's not a device test method powered and unpowered after the IEC standard.

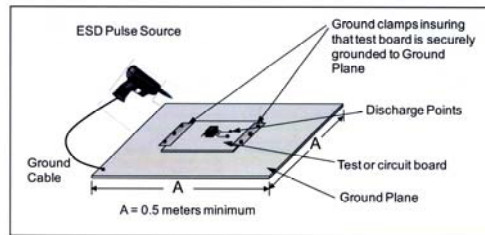


Figure 2. Typical HMM discharge /10/

IV. PROCESS STEPS IN A SMT PRODUCTION LINE

Every time PCBs are handled, electrostatic charges are generated. A SMT production line has different process steps, where such charges may be generated. As a matter of principle a PCB can always be charged by any movements. The isolating plastic, which is used as basic material, is mostly the main reason. The material is electrostatically charged by friction, p. e. by conveyor belts, although these are mostly made of conductive material.

A. Soldering Printing

One of these processes is the so-called soldering printing of PCBs with soldering paste. This procedure and the following slitting process PCB - printing colander leads to high charges. This would not be critical, unless ESDS exist on PCBs. Usually PCBs has assembled on both sides. That means that electronic components already exist during the second print or the backside-print. Very high electrostatic charges may arise while separating the printing colander from the PCB. This slitting process is typical example for the generation of electrostatic charges. It does not matter if the colander is made of metal or plastic.

B. AOI

Afterwards an optical/vision inspection, so called AOI, follows. This process does not generate any electrostatic charges by itself, but the transportation does. Optical test procedures are probably the only processes, which do not cause any electrostatic charges.

C. Pick-and-Place Machine

The PCBs arrive at the machine, which is electrostatically charged on the surface. Now a charge exchange happens inside the machine. Electronic components are electrostatically charged and are assembled with the PCB. The PCB is charged either. While placing the ESDS on the PCB the charge exchange takes place. This discharge current damages the ESDS.

Electronic components/ESDS are charged through the process „removing them from a tray or blister“. Electrostatic charges are generated during this slitting process. The ESDS are picked by the placement head and placed on the several PCBs. In the past one had experienced with the material of such placement head. Nevertheless, electrostatic charges cannot be avoided or even discharged by these. The reason therefore is the ESDS' enclosure, which is generally made of plastic (isolating).

D. ICT

PCBs may be electrostatically charged during the transport between two process steps. The following ICT (integrated circuit test machine) leads to a sudden discharge of the existing electrostatic charges on the PCB or on the single electronic component. The reason therefore is the direct contact of the metal needle (measurement probe) with the component's pins. A series resistor would not be any solution, because the discharge happens directly at the contact point between needle and pin.

E. Assembly processes

Different assembly processes causes the contact of isolating enclosure parts with static control sensitive components. Thus, an influence of the ESDS happens by the electrostatic field of isolating plastic parts. A charge transfer on the ESDS effected, which probably can cause discharges during the production process or at the customer.

F. Wire bonding process

A very critical process is the wire bonding process, during the handling of ESDS (naked chips) as well as during the wire bonding of whole assemblies. Mostly, PCBs are electrostatically charged by the enclosures or through the transport process. During the

wire bonding process a direct contact between a metal needle and an ESDS occurs again. Thus, a sudden discharge is provoked and the ESDS is damaged.

G. Further processes

Labeling processes, transport machines or systems, cutting systems or other steps can produce electrostatic potential differences. A very difficult process is “conformal coating”. First measurements have shown that the electrostatic charge are higher as 2000 volts. These differences can damage electronic parts:

- Isolating parts: plastic glass, plastic covers
- Pneumatic lines and cables: rubber transportation system, plastic rolls
- Anodized surfaces: aluminum
- Pick-up mechanisms: nozzles
- Vacuum cups
- Grippers

V. REQUIREMENTS FOR THE MACHINE (AHE) – REDUCE THE ELECTROSTATIC CHARGE

The first and only requirements are the demand for a grounding of all metal parts as well as the demand for the avoidance of plastic usage, which could generate electrostatic charges and fields. He experiences show, that it is not enough for the protection of ESDS in automated machines and systems. ESDS will not be damaged by the operator, but through the machines. The transport operation of an ESDS in a machine can happen as following:

1. Removal of the ESDS out of packaging. This is the first partition act. The ESDS has an isolating case, so it will be electrostatic charged during the removal out of the reel or the tray.
2. The electrostatic charged ESDS will be transported to the PCB. Thereby a further electrostatic charge can happen. The movement at High speed Pick-and-Place System should be enough of the generation of electrostatic charges.
3. Through the placing on the PCB, different potential between the ESDS and the PCB exist. Therefore, the potential difference leads to a discharge, which will damage the ESDS.

These examples show, that electrostatic charges always develop, when ESDS are parted or moved. Electrostatic charges will always generate because of the reason, which the components as well as the PCBs are made of an isolating material. Other acts and production steps show, that this is not the only possibility for the generation of electrostatic charges in a production process. Further critical steps are for example: the printing of PCBs, the labeling of PCBs and assemblies as well as test constructions.

Manual handling of individual components is not common anymore. PCB assemblies are handled mainly by equipment and the final phases of mechanical assembly are done by both humans and robots. In consequence of this, the Human Body Model (HBM) is not valid ESD simulation model as much as previous. The main electrostatic risk during automated manufacturing is with Charged Device Model (CDM) type of electrostatic

discharges. The additional model, but not standardized yet is Charged Board Model (CBM).

In the CBM type of ESD the assembled Printed Wiring Board (PCB) or some of the mechanics parts can be charged during handling and the discharge to ground or between the objects can happen. CBM type of discharge is typically more severe than other models for components due to high capacitance and high stored charge of PCB assemblies or mechanics. There are some main ESD control principles which are important in ESD Protected Area (EPA) as well as in automated process equipment:

1. All conductive and dissipative items are grounded.
2. Materials or parts to be contacted with ESDS are made of electrostatic dissipative material.
3. Non-essential insulating materials are excluded.
4. Where insulating materials or parts are needed, the possible charges shall be minimized by special measures, like ionization, shielding or coating.

Enclosures of machines are normally made of conductive material. The conductive enclosure should have a straight and reliable connection to ground and the distance of the insulating parts should be long enough in order not to create high electrostatic fields close to ESDS. Special attention should be paid for grounding of parts, which are separated from the enclosure or are movable, like adjustable conveyor.

There are a lot of materials which can be in contact with ESDS items. Components to be placed are stored in reels with plastic tapes covered and nozzle picks the component from reel. Components are placed on the PCB and PCB is contacted with conveyor belts and possible support pins, gripper, clamps etc. All these materials should be made of electrostatic dissipative material at least in contact area and a resistance to ground value shall be between 10^6 and $10^9 \Omega$.

Components and PCB material have plastic, insulating material and they can become charged by tribocharging, e.g. by rubbing against conveyor belt, touching on other product parts or in routing process. The charged ESDS item can subject to CDM or CBM risk. All rotating and sliding elements form an ESD risk. The tribocharging during automated manufacturing shall be minimized and metal contact to ESDS shall be prevented. Normally it is not enough, an ionizer shall be installed in the area of rotating material.

Ionizers are applied sometimes to remove electrostatic charges from machines. Electronic components and PCBs cannot be grounded. Thus, ionization is the only method minimizing electrostatic charges at the moment. Ionization is just one opportunity decreasing electrostatic charges. Intelligent ionizers are able to detect electrostatic charges in machines and to generate equivalent charges for their decrease either. The limits are shown in table 1. The mentioned ESD control steps are in common with the today's knowledge.

Table 1. Requirements for AHE (automated handling equipment's) /7/

Type of measurement	ESD item	Limits ¹
Resistance to ground (only metal parts)	equipment body (enclosure)	$R_G < 2 \Omega$
	moving parts	$R_G < 10^6 \Omega$
	all surfaces, in contact with the ESDS	$10^6 \Omega < R_G < 10^9 \Omega$
Point-to-point resistance or surface resistance	All surfaces, in contact with the ESDS	$10^6 \Omega < R_G < 10^9 \Omega$
Electrostatic potential or electrostatic voltage	Conductive parts of equipment	$V < 5$ volts
	Surfaces in contact with ESDS items or closer than 15 cm of them	$V < 50$ volts
	ESDS, PCB and mechanical parts ³	$V < 100$ volts
Electrostatic field	ESDS, PCB and mechanical parts ^{2,3}	electrostatic field strength < 10000 volts/m measured at the position of ESDS or electrostatic charge $Q < 5 * 10^{-9}$ Coulomb
	ESDS and PCB assemblies ³	

¹ Electrostatic potential, field and charge values are absolute values, so they can have either positive or negative readings.

² If the potential of process essential insulators exceeds 2000 volts the item must be kept a minimum of 30 cm from ESDS.

³ Stored charges should be less than required to cause CDM or CBM type of damage for the device.

VI. MEASUREMENT AND RESULTS

The main focus laid on measurements of electrostatic charges or on voltages on electronic components or PCBs. Picture 3 shows some measurement results, which were recorded directly in front of a pick-and-place machine. Further measurements were realized behind the soldering print machine, AOI and ICT. All measurements show, that electrostatic charges or electrostatic voltage are mostly above the limit of 100 volts.

The table 2 shows different values of electrostatic charge on the different machine positions. The electrostatic charge was always measured approx. 20 mm above the PCB. Practical measurements demonstrate that electrostatic charges are generated while moving PCBs. In particular very high electrostatic charges were measured after the soldering printing process. A serious problem occurs when the charged ESDS go into the pick and place machine. A charge exchange happens inside and causes an electrostatic discharge,

which can be very high. A further process step is the ICT. A direct metallic contact happens here and causes a very fast electrostatic discharge, which can damage the ESDS.

At the assembly process, the wire bonding is a very critical process step. The PCB is charged high by the previous steps. The wire bonding leads to a direct contact with a „metal wire” and thus to fast discharge processes. Damages on ESDS are most likely.

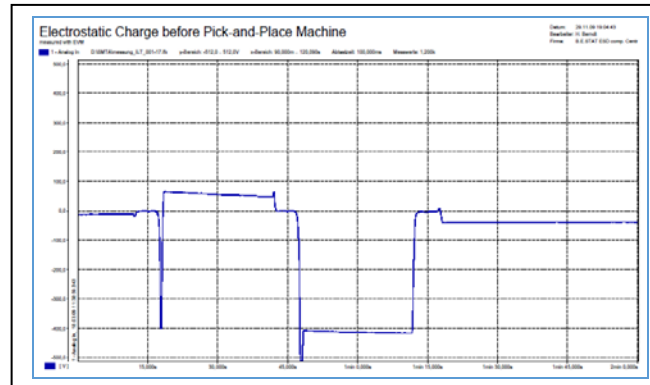


Figure 3 Electrostatic voltage of a PCB, in front of a pick-and-place machine (sample)

Table 2: Measurement results in a sample SMT Line, real electrostatic voltage

Process step (samples)	Electrostatic voltage in V		Position of the field sensor
	minimum	maximum	
Soldering printing	-2,2	257,5	Exit
AOI	-10,5	+8,5	Entry
	-1,5	-187,2	Exit
	-238	+10,5	
Pick and Place Machine	-511,5 ¹	+65,0	Entry
	-1,5	+184,5	
Pick and Place machine	-14,7	+84,5	Exit
	-115,2	+43,5	
ICT	-22,7	+134	Entry
	+15,8	+130,5	
	-116,3	+209,7	
Assembly process			
Wire bonding	-3,8	+868,0	Entry
	+4,0	+511,8 ¹	
	-212,0	+511,0 ¹	

¹ maximum value of the electrostatic field meter + field sensor

Finding the sources of charging in a SMT line, further measurements with different materials (reels/blisters) were realized. Such reels/blisters are used to provide ESDS. These measurements were really interesting, because the suppliers of those always define

them as ESD conform. Finally, the measurement results were far in excess of the allowed ranges. These packaging materials are used for transports outside of an EPA either, thus the measurement of the shielding behavior is necessary as well. A proved measurement arrangement does not exist for such measurements, so further measurements have to be realized.

VII. CONCLUSION

In conclusion, it can be said, that there are many sources for electrostatic charges in a SMT production line. The different steps lead to high or low electrostatic charge. First measurements were realized to determine the true charge. A great problem is that all machines must be stopped for the measurements. In the future it is very important, that we can measure in a normal machine, while operating. Presently, the only possibility is ionization. The grounding of all parts does not suffice; it is just a basic requirement. The moving parts PCB and ESDS cannot be grounded. Nevertheless, these are the parts, which are electrostatically charged and which cause the damages.

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