

ELECTROSTATIC DISCHARGE (ESD) – SOURCES OF ELECTROSTATIC CHARGES IN A PRODUCTION LINE (SMT)

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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.

An optimized ESD Control System for machines with the emphasis on cost-effectiveness will be presented.

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 whole 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 extern 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 2022 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. 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 are 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. 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

III. FAILURE MODELS (CDM, CBM UND FICBM)

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 PCB.

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)
- MM (Machine Model)
- CDM (Charged Device Model)
- FIM (Field Induced Model)

The first failure model only considers the charged person. The second one is a specialization of the HBM (Human Body Model). The third failure model assumes that the electronic component charges itself electrostatically and discharges itself suddenly by contacting metal. However, a person does not influence directly the charge and discharge process any more at this third one.

Reflecting the fact that quick discharges must be considered more and more in the future, all statements about electrostatic charges so far won't be sufficient any more. Very fast discharges in very short terms already exist. Those are really energy loaded and damage ESDS of course.

Nowadays, it is not enough to consider every single electronic component. One has to analyze the complete electronic assembly either. However, a suitable failure model is still missing. Two models are in preparation: the CBM (Charged Board Model) and the FICBM (Field Induce Charged Board Model). Both assume that the board (PCB) is electrostatic charged. The board has a higher capacity, so that it may store much more

electrostatic charges. Those can also be grounded by a single electronic component. The high energy causes an early damage of the whole electronic component.

A. 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 just enough to bring the electronic component in the near of a dischargeable point or object. So, 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.

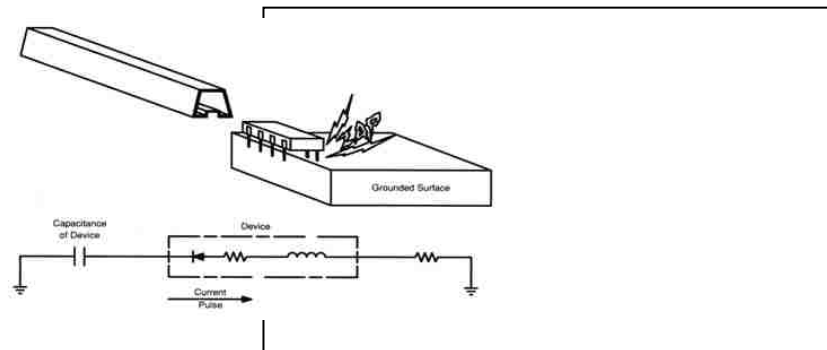


Fig. 1 Typical CDM discharge

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 (see Wunsch und Bell [6]).

B. 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 equipments. There is no direct influence of the human. The electronic components and assemblies charge themselves electrostatic. The capacity conditions of a PCB are absolute different in comparison to humans. That's why one has been 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.

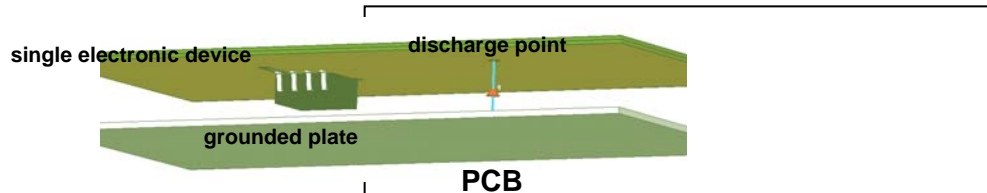


Fig. 2 Typical CBM discharge

C. 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's 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.

IV. STEPS FOR THE MACHINE GROUNDING

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 won't 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. So 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.

TABLE 1: REQUIREMENTS FOR AHE (AUTOMATED HANDLING EQUIPMENTS) [4]

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
	ESDS and PCB assemblies ³	$Q < 5 * 10^{-9}$ Coulomb

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.

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.

V. MEASUREMENT METHODS & RESULTS

A. *Measurement methods*

The following measurements are recommended to perform in order evaluating the capability of automated equipment:

1. Resistance to ground
2. Point to point resistance
3. Electrostatic potential
4. Electrostatic field
5. Accumulated charge
6. EMI (Electromagnetic Interference)

Resistance to ground measurement is one of the most important measurements in automated equipment. Each individual part is measured, like equipment body, conveyor reel, gripper, nozzle, jig, support table/pins etc. In addition to this point-to-point or surface resistance have to measure from all surfaces which take a contact with ESDS items. The appropriate probes can be used.

Electrostatic potential is measured from ESDS and PCB assemblies by qualified meter. Electrostatic field is measured from insulating materials according to manufacturer's instructions of meter. The large conductive and grounded area can affect to the measurements of potential and field.

For evaluation of real ESD risk in automated processes, the handled ESD sensitive devices or products have to be analyzed when production is ongoing. The methods are to measure the potential and charge of the devices. The charge can be measured by

individual charge meter or by measuring the discharge curve from the charged device. From the discharge curve the discharged current, energy and charge can be calculated. There are no exact acceptance levels; they must be analyzed according to ESD sensitivity of the device in case. Some requirements are in the table 1.

So called contact voltmeters (CVM) offer another opportunity to detect electrostatic charges. These CVMs are electrostatic voltmeters with a high input impedance ($> 1 * 10^{14} \Omega$, better $10^{15} \Omega$) and a low input capacity. Thus, electrostatic charges can be measured directly on the ESDS of the PCB without any damage. Those CVMs are new, so just a few tests have been realized. Electrostatic charges of about 200 V were measured on ESDS in the SMT process. Further practical tests will be realized in the next time to detect possible electrostatic charges.

B. Measurement 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.

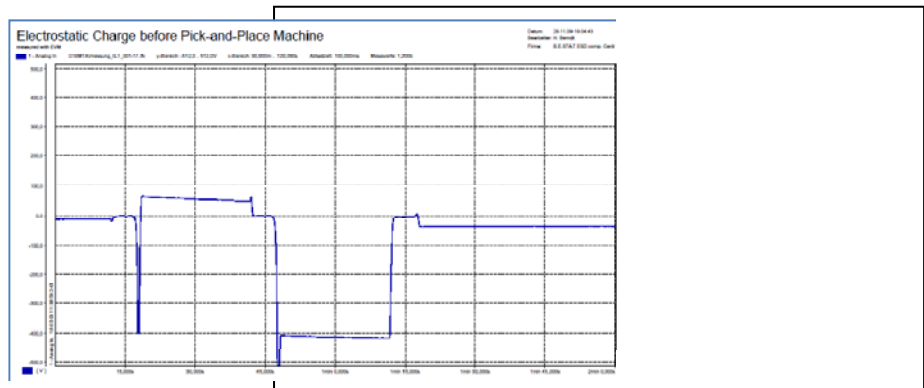


Fig. 3 Electrostatic voltage of a PCB, in front of a pick-and-place machine (sample)

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 „metall wire” and thus to fast discharge processes. Damages on ESDS are most likely.

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.

TABLE 3: MEASUREMENT RESULTS ON COMPLETE REELS WITH ESDS

Carrier material Reels	Cover tape	Carrier	ESDS
Paper	- 50 V - 200 V	- 500 V - 700 V	+ 30 V + 50 V
Thermoformed plastic	+ 800 V	+ 6000 V	+ 20 V
Thermoformed plastic	- 100 V	+ 3000 V	+ 100 V

The performance of conditions, which are close to the real process, is always considered during the measurements. Often, it is not possible to measure inside of the machines while running because of the high speed.

Picture 4 shows a possible measurement arrangement at a tape-and-reel machine.

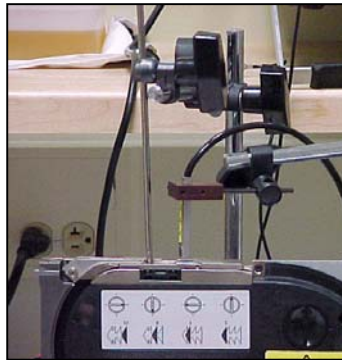


Fig. 4 Blister on a feeder with ESDS, electrostatic voltage measured with a small field sensor

VI. SOLUTIONS

At the today's point of view and the actual state of technology, ionizers can only be used in SMT lines to reduce electrostatic charges on PCBs and ESDS. Electrostatic charges are directly generated and controlled to reduce new ones. A complete control of generated electrostatic charges is essential. New technologies are necessary.

Nevertheless, packaging materials (reels/trays/magazines), which are 100 % ESD conform, have to be used. Just only a few ones meet these ESD requirements.

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.

FAILURES OF PCB AND ESDS LEAD TO A REDUCTION OF THE PRODUCT QUALITY!

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