REQUIREMENTS ON A CLASS „0“ EPA - BASICS, STANDARDS, ESD EQUIPMENT’S AND MEASUREMENTS

Hartmut Berndt, Dipl.-Ing.
B.E.STAT European ESD Competence Centre
Germany
hberndt@bestat-esd.com

INTRODUCTION

In the latest few months of last year, more and more publications report about ESD requirements for an EPA „Class 0“. What does this mean? Means the semiconductor producer “0” voltage in the area or in the EPA. The standards ANSI/ESD S20.20-2014 and the IEC standard IEC 61340-5-1 does not describe this point. According to this classification, class “0Z” means a maximum electrostatic voltage of 50 volt in the EPA. Class “0A” means an electrostatic voltage between 50 and 125 volt. The typical requirement for an EPA according to the ESD standards (ANSI and IEC) is a maximum electrostatic voltage of 100 volt. At today, the requirements for the electronic industry are higher than for other industries. Most of the EPAs meet these requirements.

Key words:
ESD Electrostatics discharge
ESD requirements on machines
SMT production line
ESD Measurements
ESD control program

BASICS

The electronic industry follows these rules when it comes to the protection of electronic components and assemblies against electrostatic discharges. Only one standard divides electronic components into certain hazard classes, the HBM standard IEC 61340-3-1 (ANSI/ESDA/JEDEC JS-001-2017):

Table 1. Classification

Classification	Voltage range (volt)	Notes
0Z	**< 50**	
0A	50 to < 125	
0B	125 to < 250	
1A	250 to < 500	
1B	500 to < 1,000	
1C	1,000 to < 2,000	
2	2,000 to < 4,000	
3A	4,000 to < 8,000	
3B	≥ 8,000	

Some semiconductor manufacturers demand a voltage of 0 volt for their electronic components within the handling area of an EPA. Is it possible to implement such requirements? Most of the ESD equipment on the market only grants the requirements up to 100 volt. Thus, how does the material have to be developed? Currently, only special ionizers are suitable to meet the target. Typical ionizers only guarantee a minimum of 100 volt, high specialized ones 10 volt (residual charge or balance) or 35 volt after the standard ANSI/ESD-S20.20-2014. The next question is, should require 0 volt in the EPA or handling area or in the machine. For requirement in the machine is the value very critical. An optimized ESD Control System for machines with focus on cost-effectiveness presented later.

All electronic components and assemblies are exposed to risks of electrostatic discharges. Producers, suppliers, distributors and users have to perform the ESD control system during the whole manufacturing process, the measurements as well as during the applications. 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 are included in this danger category. Tests show that these passive components can damaged through electrostatic discharges, specialized through the discharge current.

The structures of electronic components become smaller and smaller. 5 volt of an electrostatic charge are already enough to change the structures in small electronic components. The structures will achieve such small dimensions, so that electrostatic charges can cause permanent damages. In the year 2030, the sizes of the electronic components will be less than 10 nm or 7 nm. Then, electrostatic charges of 0.1 nC and electrostatic fields of 50 volt/cm will be enough to damage ESDS permanently.

Personal Requirements

The person is the greatest danger for electronic components. Electrostatic charges of a person are typically higher than 100 volt. The best way to reduce the electrostatic charge of a person is grounding. We have two ways for personal grounding: wrist straps and ESD shoes. The wrist strap contact with the skin of the person directly. So, the final charge of a person can be smaller than 100 volt. Many companies use ESD shoes for grounding. In figure 1, the grounding resistance is shown depending on the body voltage. Typical values for system resistance are higher than 10 MOhm. This means that the body voltage is higher than 100 volt.

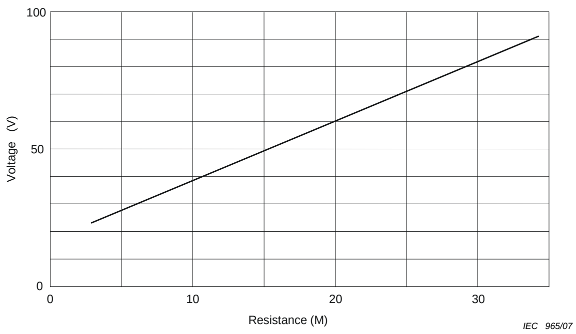


Figure 1. Body voltage relating to resistance to ground (IEC/TR 61340-5-2, 2018)

The first and best way for grounding is the connection with ESD equipment of personnel grounding. Grounding only by table mats and floor materials is not enough. Staff is controllable and workstations are ESD conform. Nevertheless, how do machines, automated handling systems, packaging systems etc. work and which requirements they have to meet?

REQUIREMENTS ON ESD - MATERIAL AND DEVICES

Requirements for a person

Persons have to be equipped with ESD required shoes and a conductive garment. The most important measure is the wristband.

Only a wristband can guarantee a permanent discharge of personal charge to a grounding point. Persons are connected by their wristband, so, no electrostatic charge can be generated. If a person has to walk around permanently because of his/her activity, the discharge can be performed through the shoes. In fact, the floor must be conductive. The shoes must have a defined resistance to ground (see table 2). Garments prevent the transfer of all electrostatic charges from normal daily clothes. If these measures are realized persons/employees are equipped against ESD.

The figure 1 (above) shows the important relationship between the body voltage or electrostatic charge of a person and the resistance to ground. So, if we estimate a lower level for electrostatic charge, we need a lower limit for the maximum resistance between the person and the floor grounding connection. Figure 1 also shows that we need an alternate grounding path from the person to the floor grounding connection in the future. If the resistance between person and shoes becomes smaller ($< 1{,}0 * 10^6\ \Omega$), the total resistance between person-shoes-floor material is going to be smaller at all ($< 1{,}0 * 10^6\ \Omega$).

Table 2. Requirements for personnel equipment

Step	Requirements R_A		Notes
	Today	Future	
Wristband	$< 3.5 * 10^7\ \Omega$	$1 * 10^6\ \Omega$?	
Shoes	$< 1.0 * 10^8\ \Omega$	$1 * 10^6\ \Omega$?	Higher requirements are necessary, when the grounding happens exclusively over the floor. Is the maximum resistance from $3.5 * 10^7\ \Omega$ or $1{,}0 * 10^8\ \Omega$ too high? Yes, the system resistance must be smaller than $1 * 10^7\ \Omega$. In the practical work process, we have different influencing factors (humidity, dust etc.)
Working clothes	$< 1.0 * 10^9\ \Omega$	$1{,}0 * 10^7\ \Omega$	The first value can only determine the surface resistance. The second important value is the charge decay time or charge distribution time from the surface. The charge decay time must be smaller than 2 s (from 1000 v to 100 v)[1].
Note 1: A new measurement method has to develop to measure the static decay time of working clothes. The existing methods are not adequate any more.			

Requirements for working places

Working places must be constructed like in the table 3 shown below. If it is constructed like this, no electrostatic charge can be developed. Furthermore, working place surfaces must guarantee that electrostatic charges can be eliminated safely. Additionally, working places must be equipped with a central grounding point like earth bonding points and earth bonding boxes. The resistance to ground of the working surface has a limited area. Table 3 shows different requirements for working places.

The resistance should not be too small. If it is too small a hard discharge (CDM method) can happen suddenly, which can damage ESDS. The limit of the upper resistance is defined in accordance to the fast and controlled, but still safe, discharge of electrostatic charge. At the same time the decay time is determined.

Table 3. Requirements for working place surfaces

Step	Requirements R_A		Notes
	Today	Future	
Working place surface	$< 1 * 10^9\ \Omega$	$< 1 * 10^6\ \Omega$?	$1 * 10^9\ \Omega$ is too high and produce more than 1000 volt of electrostatic voltage. Surfaces with a resistance to ground about $< 1 * 10^6\ \Omega$ lead to electrostatic charges higher than 100 volt. Additionally, the discharge behavior of the surfaces have to be determined.
Decay time	< 2s (from 1000 volt to 100 volt)	< 2s (from 100 volt to 10 volt)	at a resistance value higher than $1 * 10^9\ \Omega$ The measurement of the static decay time is necessary at $1 * 10^6\ \Omega$.

Requirements for floors

The floor is an important part of an ESD area. It is necessary for persons who do not wear any conductive shoes and whose discharge mostly happens over the floor. The electrical characteristics are show in table 4. There are many experiences with conductive floors. Basically, conductive coverings are suitable because hard coatings (epoxy) have additional problems with the contact behavior. Some materials are not suitable. Previous tests made many questions like: Do the measurement probes and sample are suitable at all? Do the probes really establish the contact person-shoes-floor? Is the contact material of the probe maybe incorrect? Some interested parties have the opinion that contact material on probes do not agree with the reality. Other assumes that probes are not the reflection of the contact person-shoes-floor. A further question cause quite a stir: Can a person be standardized? Additional tests have been realized and will be realized in the future [1].

The basic requirements to conductive floors are not influenced through the tests. Electrostatic charges should be discharged over a conductive floor.

Extensive attempts show, that higher requirements have to be fulfilled at working places, where people work by standing. A higher resistance ($> 1{,}0 * 10^8\ \Omega$) would develop electrostatic charge higher than 100 volt. There are different types of floors – floor coverings and floor coatings, which can be thin or thick. But the contact resistance between person-shoes-floors is decisive. The reason for it is the basic principle of the discharge of charged persons. Tests with different floor materials showed that only a few of them are suitable. [2]

Table 4. Requirements for floors

Step	Requirements R_A		Notes
	Today	Future	
Floor	$< 1 * 10^9\ \Omega$	$1 * 10^6 \ldots 1 * 10^7\ \Omega$	The system resistance is the most important value in the future for personnel grounding.
Higher requirements	100 volt	10 volt	Today: at a maximum electrostatic charge of 100 volt from a person, 10 volt will be the maximum in the future.
Decay time	< 2 s (from 1000 volt to 100 volt)	< 2 s (from 100 volt to 10 volt)	The measurement of the static decay time is required above a resistance from $1 * 10^6\ \Omega$.

Requirements for packaging material

The packaging requirements correlate with the IEC 61340-5-1 [4] (enumeration according to the standard) and will be introduced in the new packaging standard IEC 61340-5-3 (see table 5 and table 6).

A third requirement is the question of tailoring. In the future, companies will have more responsibility for the art of the packaging material.

Table 5. Requirements for packaging material

Material property	**Resistance limits**	**Charge decay time**	**Requirements for class zero**	**Notes**
Electrostatic conductive	$1 \times 10^{2}\ \Omega \leq R_S < 1 \times 10^{4}\ \Omega$	-	$(1 \times 10^{2}\ \Omega) \leq R_S < 1 \times 10^{4}\ \Omega$	Lower resistance range, add charge decay time
Electrostatic dissipative	$1 \times 10^{4}\ \Omega \leq R_S < 1 \times 10^{11}\ \Omega$	$(> 1 \times 10^{9}\ \Omega)$ < 2 s	$1 \times 10^{4}\ \Omega \leq R_S < (1 \times 10^{11}\ \Omega)$	Lower resistance range, add charge decay time
Electrostatic shielding	< 50 nJ	-	< 20 nJ (?)	Shielding or field shielding properties
Note: R_S … surface resistance (IEC 61340-2-3)				

Table 6. Packaging material inside and outside of an EPA

6.1 Inside an EPA	**6.2 Outside an EPA**
Packaging used within an EPA (that satisfies the minimum requirements of ANSI/ESD S20.20) shall be: 1. Low charge generation. 2. Dissipative or conductive materials for intimate contact. Items sensitive to < 100 volt Human Body Model may need additional protection depending on application and program plan requirements.	Transportation of sensitive products outside of an EPA shall require packaging that provides: 1. Low charge generation. 2. Dissipative or conductive materials for intimate contact. 1. 3. A structure that provides electrostatic discharge shielding.
Notes: If electric field shielding materials used to provide discharge shielding, a material that provides a barrier to current flow (insulator) must use in combination with the electric field shielding material. Where this standard does not provide a test method, the user must determine the electrostatic discharge shielding properties of the packaging. See Appendix G for guidance about determining discharge shielding properties.	

Requirements for an EPA

For having an optimized protection of ESDS, ESD working places and working areas are necessary. The basic equipment: an ESD working place, which contains a conductive surface covering, a wristband and a grounding system. All equipment must connected with a grounding point. That grounding point guarantees the same potential at all points of the working place.

The installation of ESD areas (EPA) is wiser. Because of the design of all materials and equipment, electrostatic potential above 100 volt cannot developed. Nevertheless, if some should developed caused by unsuitable packaging materials, one can discharge them without any danger.

After having equipped everything according to the ESD requirements - all persons, working places and so on - new sources of electrostatic charge will see. Persons and working places must handle like the ESD requirements. The charges can controlled.

The introduction and the control of these five steps were already describe in the concept “5 Steps Plan of an ESD Control System” [1]. The result is the following ESD control system:

1. Analysis of ESDS, their damage limits and the existing manufacturing process.
2. Creation of a program and the introduction steps of the ESD control system.
3. Personnel training
4. Introduction of the ESD control systems
5. Control and certification of the introduced ESD control systems.

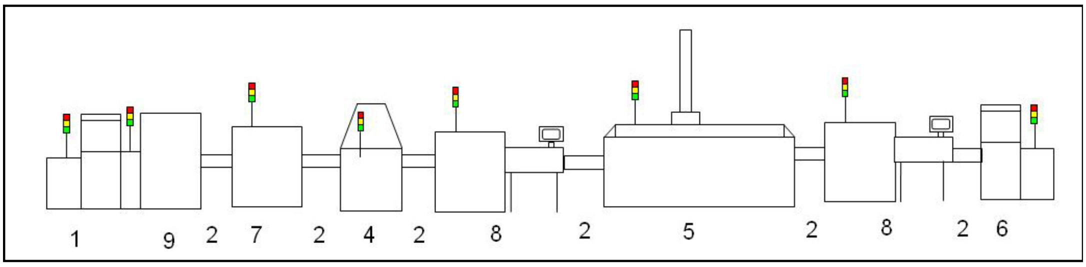
The introduction of this ESD control system is more complex than the single system requirements of the IEC 61340-5-1 and the control program of the ANSI/ESD S20.20. Only both standards and the additional existing concept guarantee a safe ESD control system as well as the protection of ESDS against electrostatic charges. We cannot find enough information and requirements for the machines in the existing standards.

Requirements for humidity and temperature

Recently, some publications report that the increase of humidity in rooms should make a significant contribution to the reduction of ESD failures. That is not true in this way! An increase of the relative humidity is only conditionally possible and depends on the process parameters of a SMT production. Further on, spraying systems are used to spray out the very fine water particles (called aerosols) while using ultrapure water, etc. This water is usually high impedance and has the additional property of being electrostatically charged by spraying through the metal nozzles. The question here has to be, whether additional electrostatic charges, which electrostatically charge the ESDS or assemblies, are generated or not.

Requirements for machines

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



Notes: 1 Line Loader, 2 Transport and Waiting System; 4 SMD Pick and Place Machine; 5 SMD Oven; 6 End of Line Loader; 7 AOI; 8 Manual Optical Inspection Systems; 9 Printers

Figure 2. SMT production line (sample)

A. Soldering Printing

One of these processes is the 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 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 electrostatically charged on the surface. Now a charge exchange happens inside the machine. Electronic components are electrostatically charged and assembled with the PCB. The PCB charged either. While placing the ESDS on the PCB the charge exchange takes place. This discharge current damages the ESDS.

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

D. ICT

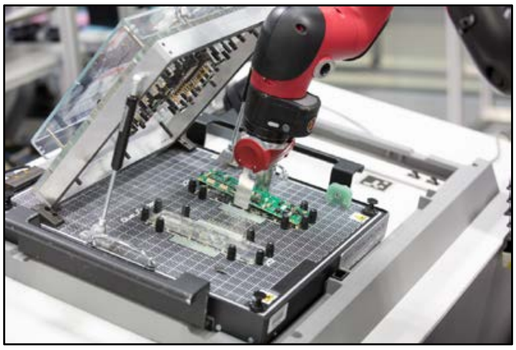
PCBs may electrostatically charge during the transport between two process steps. The following ICT (integrated circuit test machine) leads to a sudden discharge of the existing electrostatic charges on the PCB or on the single electronic component. The reason therefore is the direct contact of the metal 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. 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

G. Robotic systems
The automated robotic systems in a SMT line, does not reduce the risk of electrostatic charge. The robotic systems replace the human; the source of electrostatic charge is now the robot. The robot move fastener as a human a produce higher electrostatic charge in the process. The robot cannot discharge the charge from the electronic part or PCB. This part are isolated and the human and the robot cannot contact the isolated material.



Source: smart-smt-factory-forum
Figure 3. Robotic system

ESD control program for machines
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 which are in contact with ESDS must be made of electrostatic dissipative material.
3. Non-essential insulating materials are excluded.
4. Where insulating materials or parts are needed, the possible charges must 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 on 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 should be between $1 * 10^6$ Ω and $1 * 10^9$ Ω.

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 should be minimized and metal contact to ESDS should be prevented. Normally, these preventions are not enough. Thus, an ionizer should installed in the area of rotating material. Ionizers 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. Intelligent ionizers are able to detect electrostatic charges in machines and to generate equivalent charges for their decrease either.

Requirements/Questions for an ESD control program for machines:
1. Are all parts grounded?
2. Is there no plastic material charged? Is only ESD plastic material used?
3. How does delivery of ESDS and PCBs happen?
4. Is the packaging material ESD conform?
5. How are the requirements for the packaging material for non ESDS defined?
6. How is the transport der ESDS inside of the machine defined?

7. If non ESD material is used (i.e. for high voltage wires), do the transportation ways of the ESDS have enough distance from this?
8. Are the PCB and the ESDS of the same potential when they get in contact? (i.e. in a pick-and-place-machine)
9. Are the PCB and the ESDS discharged enough?
10. Are the transport conveyors, belts and systems between the machines on the same electric potential?

Based on these questions, ESD requirements will be created for machines.

MEASUREMENTS

The most instruments on the market for measure electrostatic voltage, electrostatic charge and for resistance are not qualified for these correct measurements. Only special contact volt meters (CVM) or electrostatic static volt meters (EVM) are able to measure this very small electrostatic charge.

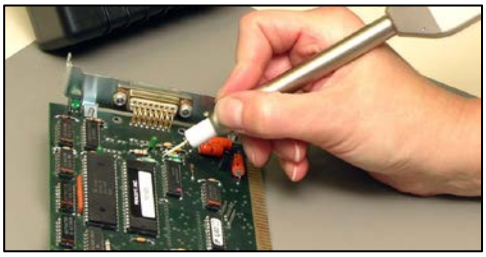


Figure 4. Measuring PC conductor with high an impedance contact volt meter

The first step is the measurement with a contact volt meter. Furthermore, high sensitive electrostatic volt meter can be used. They do not damage ESDS during the measurement.

CONCLUSIONS

The requirements “0 volt” can be achieved, when die maximum value will be required. Unfortunately, today we do not have any ESD material, which requires these limits.

The biggest problems are machines and automated handling equipment (AHE), because very small charges are generated in these machines, independent from persons. These small and fast discharge procedures are energy-intensive. They cause damages of electrostatic sensitive devices and assemblies. The grounding of all metal parts does not suffice. New processes, which either discharge very small electrostatic charges fast or prevent theses discharges, have to be developed.

The only way to meet such requirements is precision-ionization. All other ESD equipment have more than 0 volt. Even with a limit value of 50 volt or 125 volt (Level 0Z or 0A) it is hard to find suitable ESD material. A further attempt is to classify ESD control areas in different zones.

In addition, the increase of relative humidity by spraying is no solution to reduce electrostatic problems in EPAs. Many processes are also closed and cannot be influenced.

REFERENCES

[1] H. Berndt, Five Steps for the Introduction of an ESD Control System, Proceedings APEX 2004, Anaheim, CA, U.S.A.

[2] H. Berndt, A study of the Variables of Electrodes used in the Measurement of Table and Floor Materials and How They Affect the Test Results, 23. EOS/ESD-Symposium 2001, Portland, OR

[3] H. Berndt; VDE-Schriftenreihe - Normen verständlich - Band 71 Elektrostatik - Ursachen, Wirkungen, Schutzmaßnahmen, Messungen, Prüfungen, Normung, VDE-Verlag, 2017

[4] IEC 61340-5-1 Electrostatics – 06-2016: Part 5: Specification for the protection of electronic devices from electrostatic phenomena, Section 1: General requirements

[5] IEC 61340-5-2 Electrostatics – 03-2018: Part 5: Specification for the protection of electronic devices from electrostatic phenomena, Section 2: User guide

[6] ANSI/ESD S20.20-2014 ESD Association Standards for the Development of an Electrostatic Discharge Control Program for – Protection of Electrical and Electronic Parts, Assemblies and Equipment’s

[7] ANSI/ESD SP10.1-2016 ESD Association Standard practice for Protection of Electrostatic Discharge Susceptible Items – Automated Handling Equipment (AHE)

[8] H. Berndt, Electrostatic Discharge (ESD) and the Technology Roadmap to 2020, Pan Pacific Microelectronic Symposium, January 2008