Electrostatic Discharge (ESD), Factory Issues, Measurement Methods and Product Quality – Roadmaps and Solutions for 2025 to 2030

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Introduction
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. The paper will give an overview about possible causes for ESD. 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 electric tests (ICT). The electronic components are always assembled directly and without any covering on the PCBs. Thus, the wire bonding process leads to damage of the electronic components. The processing steps, where the PCBs are covered with chassis must be inspected also. Such chassis are mostly made of isolating materials, like plastics. Thus, those can be highly electrostatic charged, while assembling. In summary an optimized ESD Control System for ESD working areas and machines with the emphasis on cost-effectiveness will be compared. Topics: An optimized ESD control system, with an emphasis on cost-effectiveness, Introduction of an optimized ESD Control System for ESD working areas, Solutions for machines and automated processes, Measurement methods in SMT production line and ESD audits, Product quality.

Standardization
Normally, all requirements are defined in the valid standards. However, this is not the case here. The worldwide standards IEC 61340-5-1 /6/ and IEC 61340-5-2 /7/ only give guidance on how an ESD area should be set up. The same goes for the American standard ANSI/ESD S20.20-2007 /9/. Both standards also only provide hints on how an ESD Control System should be created, whereby each user can decide by themselves, which parts his or her ESD program have to include. Thus, the implementation of an ESD Control System depends on the needs of each company and is hardly comparable to others. There are no minimum requirements in principle. Regarding a various number of publications, a classification at different production stages is even required. Nevertheless, there aren't any advanced requirements or at least basic requirements at all. Basically it is everyone for themselves!

The paper tries to give answers to these questions. What are the basic requirements on an ESD area? How should it be equipped? What are at least the basic requirements on an ESD Control System?

Basics – ESD failures in a SMT production
Electronic components can be damaged both at the work site and in the production line. As today's production lines include automatic handling equipment (AHE) as well as manual work places, both types must be considered.

Two basic principles exist:

Basic principal 1: Only a complete ESD Control System will guarantee an adequate protection for electrostatic sensitive devices (ESDS).

Basic principal 2: The grounding of a person with a wristband is the best possibility for the discharge and the charge avoidance.

1. Manual work places
A distinction is made between work areas where ESDS are directly finished and materials that may not be electrostatically charged. The area with direct contact to the ESDS is the work surface as well as the storage containers and tools. The other work equipment like chairs and trolleys may not be electrostatically charged. The main source of electrostatic charge is the person. Thus, the person must be securely grounded through the wrist band, at best. The best and also the only possibility to ground a person in sedentary activity is the connection between the person and the earth potential. Besides that, in a standing position, it would be also be possible to connect the person via ESD shoes and ESD floor to the potential equalization. The daily clothing of the person has to be covered with an ESD coat on the upper torso.

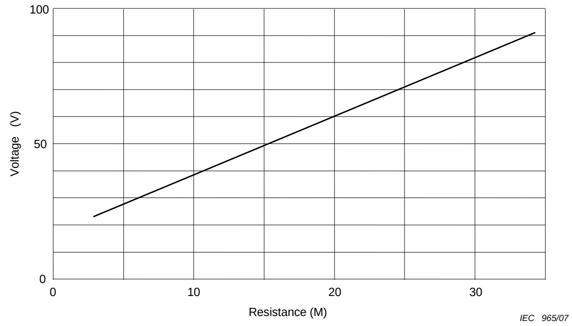


Figure 1 Electrostatic voltage depends on the resistance to ground (IEC 61340-5-2 TR, 2007) /7/

At work surfaces that contact ESDS directly, care has to be taken that no electrostatic charges incur on them. If the ESDS are charged before storing them on the work surface, these electrostatic charges have to be safely discharged. Metal surfaces are not suitable.

Table 1. Requirements on manual work places

Step	**Requirements R_A**		**Notes**
	Today	Future	
Wristband	$< 3.5 * 10^7\ \Omega$	$1 * 10^6 \Omega$?	See Figure 1
Working clothes	$< 1.0 * 10^9\ \Omega$	$< 1.0 * 10^9 \Omega$?	The first value can only determinate 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]. The third value is the electrostatic shielding properties.
Working place surface	$> 7.5 * 10^5\ \Omega$ and $< 1 * 10^9\ \Omega$	$< 1 * 10^6 \Omega$?	$1 * 10^9\ \Omega$ 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 v. 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 $1 * 10^6\ \Omega$.
Grounding[3]	$< 2\ \Omega$	?	

Notes:
[1] A new measurement method has to be developed to measure the static decay time and electrostatic shielding properties of working clothes. The existing methods are not adequate any more.
[2] The limits are required today from the IEC 61340-5-1 and ANSI/ESD S20.20-2007
[3] Metal surfaces are not approved.

Working places must be constructed like on the Figure shown below. So, no electrostatic charge can develop. 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. Figure 2 shows such an optimal equipped ESD working place. The resistance to ground of the working surface has a limited area.

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

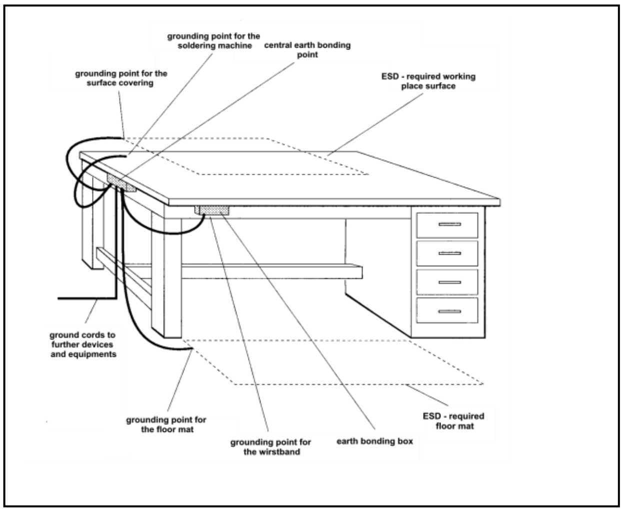


Figure 2 ESD required working place with a central grounding point /8/

2. ESD floors material:

The floor is an important part of an ESD area. It is necessary for persons who do not wear wrist straps and whose discharge mostly happens over the floor. The electrical characteristics are in Table 2. There are many experiences with conductive floors. Basically, conductive coverings are suitable because hard coatings (Epoxy) have additional problems with the contact behavior of the probes. Some materials are not suitable. Previous tests have developed many questions for the future like: Are the measurement probes and sample suitable at all? Do the probes really establish the contact person – shoes – floor – grounding point? Is the contact material of the probe maybe incorrect? Some interested parties have the opinion that contact material on probes do not agree with reality. Others assumes that probes are not the reflection of the contact person – shoes – floor – grounding point. A further question causes quite a stir: Can a person be standardized? Additional tests have been realized and will be realized in the future. The basic requirements to conductive floors are not influenced through the tests. Electrostatic charges should be discharged over a conductive floor.

Table 2. Requirements to ESD floors

Step	**Requirements R_A**		Notes
	Today	In the future	
Floor	$< 1 * 10^9\ \Omega$	$1 * 10^6 \ldots 1 * 10^7\ \Omega$	
Higher requirements	$< 3.5 * 10^7\ \Omega$	?	at a maximum electrostatic charge/voltage of 100 V
Decay time	< 2 s (from 1000 V to 100 V)	< 2 s (from 100 V to 10 V)	
ESD footwear	?	?	

Extensive attempts show, that higher requirements have to be fulfilled at working places, where people work by standing. A higher resistance would develop electrostatic charge higher than 100 V. There are different types of floors: floor coverings and floor coatings, which can be thin or thick. But the contact resistance between person – shoes – floor – grounding point 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. The additional measurements of the decay time are urgently required to qualify the material.

Requirements on the EPA:

For having optimal 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 equipments must be connected with a grounding point. That grounding point guarantees the same potential at all points of the working place.

The installations of ESD areas (EPA) are wiser. Because of the design of all materials and equipments electrostatic potential over 100 V cannot be developed. Nevertheless, if some should be developed caused by unsuitable packaging materials, one can discharge them without any danger.

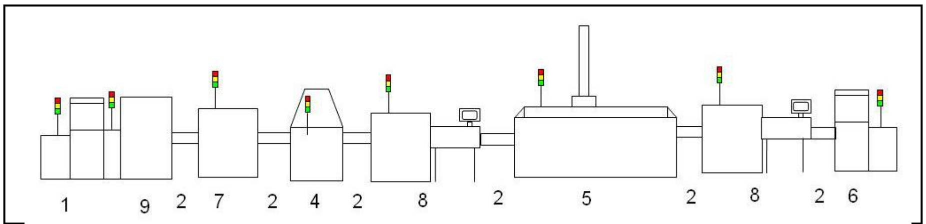
After having equipped, according to the ESD requirements, all persons, and working places and so on, new sources of electrostatic charge will be seen. Persons and working places must be handled like the ESD requirements. The charges can be controlled.

2. Automated Handling Machines or other machines (printer, AOI, ICT, Cutting and soldering machines etc.)

The first and only requirements are the demand for grounding of all metal parts as well as the demand for the avoidance of plastic usage, which could generate electrostatic charges and fields. Experience shows that this 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 follows:

1. Removal of the ESDS out of packaging. This is the first partial 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 develop. The movement at the high speed Pick-and-Place System should be enough for the generation of electrostatic charges.
3. By placing it 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 transported. Electrostatic charges will always generate because of the reason that components as well as 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.



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 3 SMD production line (sample)

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, e.g. by conveyor belts, although these are mostly made of conductive material.

Soldering Printing

One of these processes is the printing of PCBs with soldering paste. This procedure with the printing of paste through the stencil onto the PCB leads to high charges. This would not be critical, unless ESDS existed 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 stencil from the PCB. This stencil release process is a typical example for the generation of electrostatic charges.

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.

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 also. 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 of removing them from a tray . Electrostatic charges are generated during this process. The ESDS are picked by the placement head and placed on several PCBs. Electrostatic charges cannot be avoided or even discharged by the placement heads. The reason therefore is the ESDS enclosure, which is generally made of plastic (isolating).

ICT

PCBs may be electrostatically charged during the transport between two process steps. The following ICT (in 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 pins.
A series resistor would not be any solution, because the discharge happens directly at the contact point between needle and component pin.

Assembly processes
Different assembly processes cause charges because 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.

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.

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

Measurements
Tables 1 and 2 describe the current as well as the future requirements to ESD equipment. However, it has to be considered that the usual and present measurement methods have to be replaced. Actually, the measured values should only reflect our requirements and wishes to avoid electrostatic charges, or, if it is not possible, to evaluate the discharge performance of materials. That means that we have to accurately measure the discharge time. The usual resistance should just simplify the measurement. The experience of recent years, however, shows that this is not a criterion for a true assessment of ESD materials. The resistance was always a substitute value for the assessment of the conductivity or the discharge of different materials.

Measurement methods
Typically, resistance measurements are realized. At such measurements the grounding resistance from a person to a metal plate or an existing floor is measured. The first test is an entrance test before entering an EPA. Another measurement is realized at the inspection of the EPA's system resistance. Additionally, all ESD equipment is tested through a resistance measurement. Clothing is also important for the personnel equipment. The measurement of the clothing's surface resistance is just now the only method to confirm the clothing's ESD characteristics. Some special clothing permits a measurement to an earth grounding point. Such measurements are often not sufficient. An employee can be also electrostatic charged. Independent of wearing ESD clothing, electrostatic charge can be stored by the employee's 'normal clothing'. A part of this electrostatic charge is grounded by the ESD clothing, but nevertheless, the person is still electrostatic charged. The amount of the electrostatic charge can be measured typically with an electrostatic voltmeter or a measurement construction of a Charge Plate Monitor.

Special measurement methods in a factory
The following measurements are recommended to perform in order to evaluate the capability of automated equipment:

1. Resistance to ground
2. Point to point resistance
3. Electrostatic potential
4. Electrostatic field
5. Accumulated charge

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 additional to this point-to-point or surface resistance we have to measure from all surfaces which are in contact with ESDS items. The appropriate probes can be used.

Electrostatic potential is measured from ESDS and PCB assemblies by a qualified meter. Electrostatic field is measured from insulating materials according to the manufacturer's instructions for the meter. The large conductive and grounded area can affect 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 3.

Table 3. Requirements for AHE (automated handling equipments) /10/

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.

So called contact voltmeters (CVM) offer another opportunity to detect electrostatic charges. These CVMs are electrostatic voltmeters with a high input impedance (> $1 \times 10^{14}\ \Omega$, or 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 going forward to detect possible electrostatic charges. 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.

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

Roadmaps – Solutions to 2025/2030

Currently three various roadmaps exist from the following associations with different backgrounds: ESDA, ITRS and IC (Industrial Council). The most important map for the semiconductor industries is the ITRS roadmap. The other roadmaps are published by private organizations. The future requirements for ESD charge and ESD field for the ITRS Roadmap are shown in Table 4. We will achieve limits between 10 V electrostatic charges or 10 V/m electrostatic field strength for the ESD failures for the electronic devices.

Within an EPA it will be necessary in the future not to exceed theses values. Nevertheless, that won't be easy, because the existing ESD equipment is not able to guarantee these minimum values.

The other roadmaps refer to a single electronic component or the complete electronic assembly only considering information from OEMs. However, there are many small EMS companies that do not screen their defective components, because it is simply too expensive.

Table 4 Development of the Sensibility of ESDS, Roadmap of ITRS /1/

Year	**2000**	**2004**	**2009**	**2012**	**2015**	**2020**	**2026**	**2030**
Electrostatic Field (V/cm)[1]	200	100	55	38	28	20	10	-
Electrostatic Field (V/m)[1]	-	-	-	-	-	-	1000	< 500
Electrostatic Charge (nC)	2,5	1	0,25	0,125	0,1	0,08	0,04	< 0,04
Sizes (of Gateoxid) (nm)	180	90	50	32	25	14	11	< 10

Notes:
[1] The electrostatic field will be shown from 2026 in V/m. The correlation factor is 100. /1/

This roadmap shows a very high sensibility of the electronic devices in the next ten to twenty years. Although most devices include protection circuits, the devices become more and more sensitive. The protection circuits do not work until the connection with ground and supply voltage. Without any power connection, the protection circuits have the same sensibility as the other parts of the circuit. This is very important for the ascertainment of the minimum ESD breakdown voltage. The ITRS roadmap is the most important and independent roadmap, which shows the ESD sensibility limits of the electronic industries.

The sensibility of the ESDS increases with the decrease of the sizes of circuits. The critical part of the ESDS is mostly the gate oxide. The pn-junction ROM is the critical part of the bipolar devices. The ESDS can be damaged directly through the discharge current from an electrostatic discharge. The ESDS can also be damaged by a non-direct contact event, with an electrostatic field event. Both failure mechanisms will be described in the ITRS requirements.

ESD Association Roadmap /2/ and Roadmap from the Industrial Council /3, 4, 5/
The ESD Association acts on the requirements of the OEM (companies). Certainly, this roadmap is affected by long lasting experiences of its members. The ESDA assumes that the HBM(Human Body Model) played an important role previously. A change from the HBM to the CDM (Charged Device Model) is observed in recent years. So, ESDS are influenced under real conditions by machines in a manufacturer, so called Metal Discharge Events or "HMM". The greatest event nowadays is the discharge on metal parts in an AHE (Automated Handling Equipment) or the charge exchange to PCBs. Nevertheless, the ESDA does not go into this more. Further on, charges and discharges of persons are surveyed under new points of view. Past limits are decreased. Already less than 500 volts are able to damage ESDS, not at least 2000 volts as believed in the past. Considerations on the roadmap only last until 2015. Additionally, questions remain unanswered, e. g. how should an EPA be equipped in the next few years; which demands will be on ESD materials and ESD equipment?

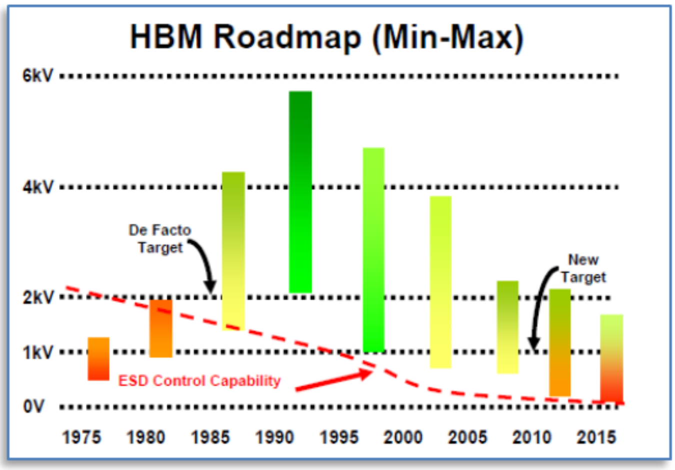


Figure 5 Human Body Model Sensitivity Limits Projections /2/

Table 5: Summary of ESD HBM classification

HBM Level[1]	**Classification**	**Comments**
2 kV	Exceeds requirement	With basic ESD control methods
1 kV	Meets requirement, with margin	
500 V	Adequately meets requirement	
100 V – < 500 V	Sensitive ESDS	Requires advanced ESD control methods[2]

Notes:
[1] The proposed HBM levels fully ensure that more than sufficient MM robustness (> 30 V) is also maintained with basic ESD control methods.
[2] Advanced ESD control methods are ANSI/ESD S20.20 and/or IEC 61340-5-1

The best would be a comparison of the HBM models. Every roadmap states an own limit value and these differ from each other. All models and roadmaps set out from different starting points or starting values. Nevertheless, the comparison below shows, that the ITRS roadmap comes from the real production technology and its physical basics. Compared with this, the other roadmaps coming from the industry are "harmless" and are themed to the application or the realization of the requirements. However, these roadmaps do not consider the sensibility of ESDS. Other criteria like the image of the semiconductor manufacturer are more important instead.

Table 6: Comparison of the limits for HBM models

HBM model	**Limits**	**Notes**
ITRS roadmap	28 V/cm (2015)	Edition 2012; no special limit for each model
ESDA	2 kV, 1 kV, 500 V	
Industrial Council	1 kV, 500 V (100 V - 500 V)	

However, the HBM model is no longer the most important criterion. The procedures and mechanism in the AHE become more and more decisive. Thus, the requirements for complete ESD safety arise increasingly from the machine processes. These processes are always considered, but many machine manufacturers ignore the requirements. The Industrial Council also does its bit. Regarding the amount of returns or complaints of the EMS companies, the failures in time seem to be really low. Either the amount of components are extremely small or the return/complaint happens via a reseller. Including the distributors in the static view is too expensive. However, the entire complaints account for a majority of the failures, but these are not considered in the roadmap of the Industrial Council.

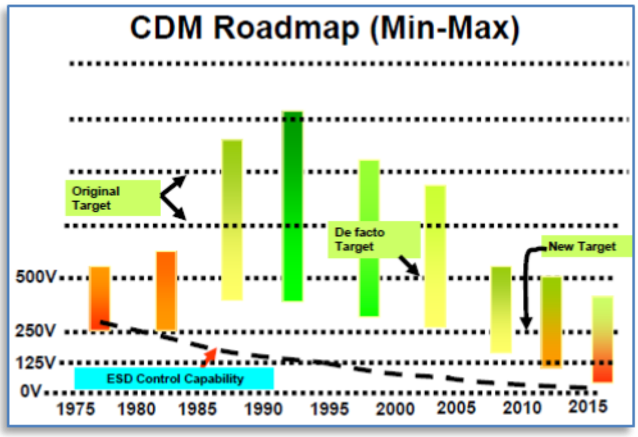


Figure 6 Charged Device Model Sensitivity Limit Projections /2/

The third roadmap is the program of the Industrial Councils of the OEMs. This council is composed of some semiconductor producers, EMS companies and service companies. These companies act on the claims of the industry. Hazardous parts are described with either the HBM and the CDM, whereas different papers are issued for both failure models. A decisive disadvantage is the fact that those companies act on rejections or claims. However, those happen rarely. The most companies, particularly small and medium companies, do not object or are not able to reach the semiconductor producers directly. Thus, from the members' sight of the council only a few claims are known.

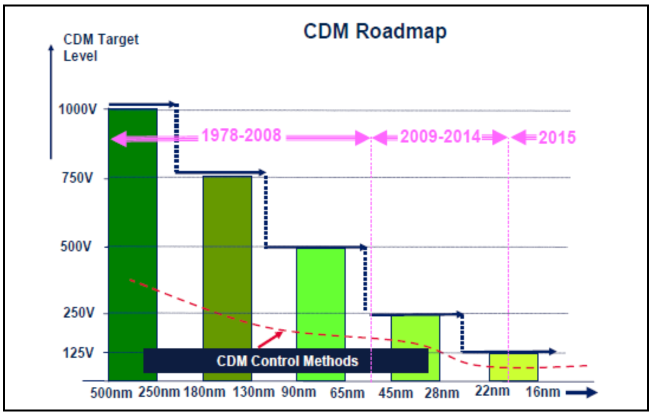


Figure 7: Technology scaling effects on practical CDM levels and the associated CDM control requirements /5/

Figure 7 shows only a part of the true state for the actual requirements to the ESD protection.

ESD Control System
The introduction and the control of these 5 steps were already described previously in the concept "5 Steps Plan of an ESD Control System" /11/. 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 System 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.

Conclusion
The statements are intended to highlight the problems in an EPA and the handling of electronic components in the coming years. The components become more and more sensitive to electrostatic charges and fields. However, the current ESD measures are not sufficient, and thus they are not able to protect the ESDS in the coming years.

Many companies have already installed ESD Control Systems and ESD equipment. But this will not suffice, because the plans must be constantly reviewed and adapted to the current ESD requirements. Nevertheless, the ESD equipment on the market will no longer meet the ESD requirements in the coming years. They must be developed. Furthermore, the failure models are constantly changing. So far, the HBM was the most important one, but the CDM also becomes more and more important.

The actual sources of static electricity are another problem. People and work places are well controlled, but the machinery, equipment, etc are the next generation of electrostatic charges. The existing measurement systems are partially sufficient for the verification of persons and work places. But they are no longer sufficient to determine the electrostatic charges and fields in the very fast processes of plants and machinery. The question is, do we still measure static or would a dynamic measurement be better? At what speeds, frequencies, sampling rates, etc., should we measure?

Even conventional measurement technology is no longer sufficient today to measure electrostatic charging and discharging. Sometimes there are new materials that cannot be assessed according to the methods of resistance, such as conductive and dissipative plastic coatings.

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Electrostatic Discharge (ESD), Factory Issues, Measurement Methods and Product Quality – Roadmaps and Solutions for 2025 to 2030

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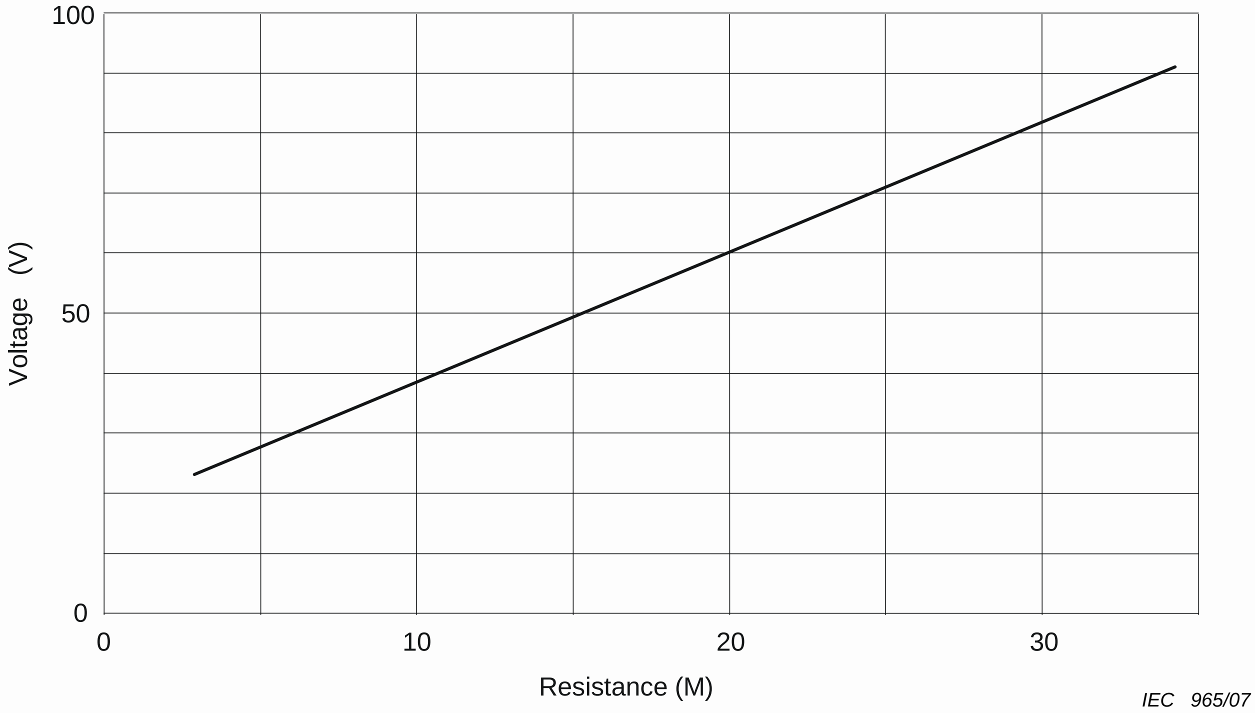
- **Introduction**
- **Standardization**
- **Basics**
- **EPA Requirements**
- **Measurements**
- **ESD Roadmaps**
- **Conclusions**

Basics – ESD failures

Two basic principals:

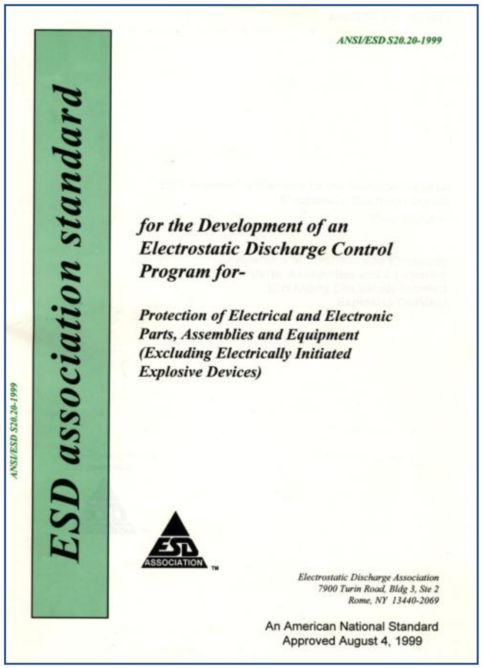
Basic principal 1:
Only a complete ESD control program will guarantee an adequate protection for electrostatic sensitive devices (ESDS).

Basic principal 2:
The grounding of a person with a wristband is the best possibility for the discharge and the charge avoidance.

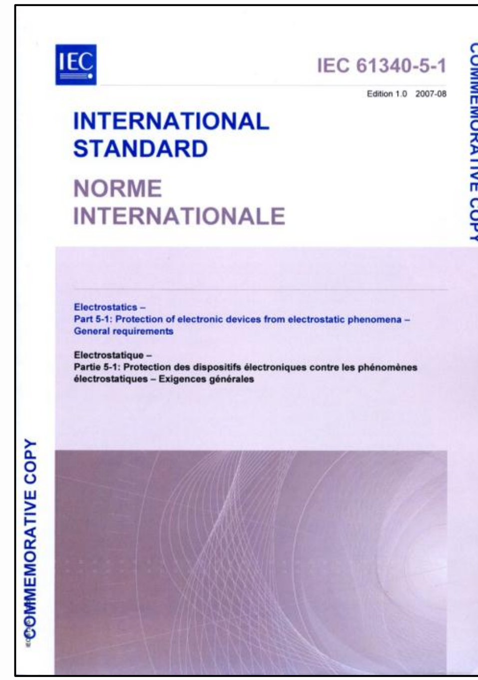


Picture 1 Electrostatic voltage depend from resistance to ground (IEC 61340-5-2 TR, 2007)

Standardization



ANSI ESD S20.20 – (2014)

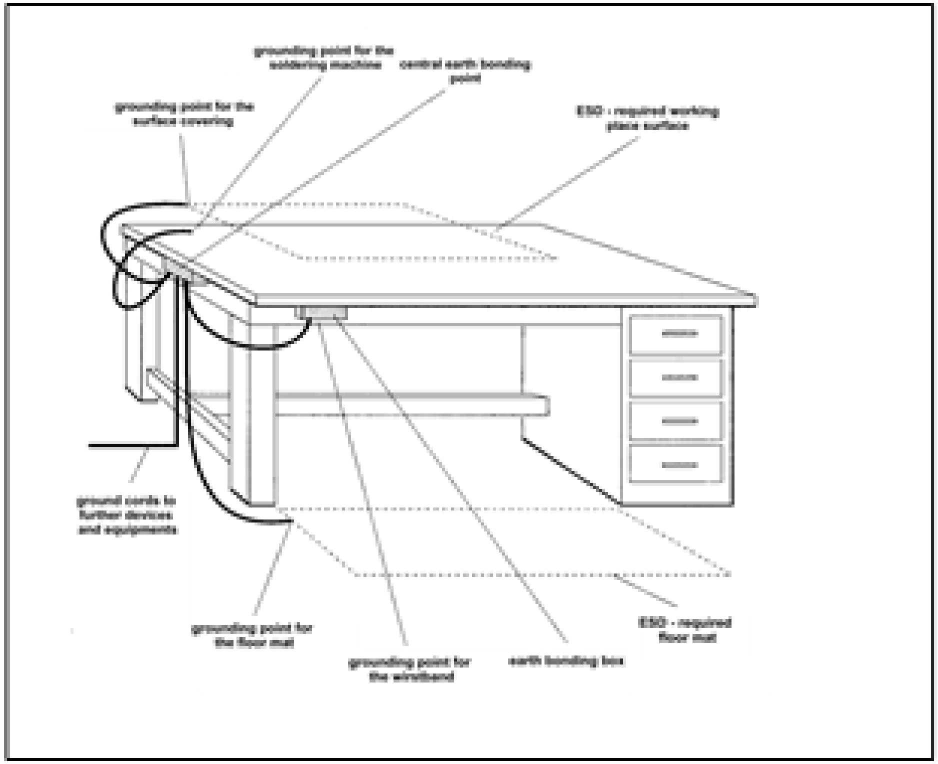


IEC 61340-5-1 (2014)+ IEC 61340-5-2

Step	**Requirements R_A**		**Notes**
	Today	Future	
Wristband	$< 3.5 * 10^{7}\ \Omega$	$1 * 10^{6}\ \Omega$?	See picture 1
Working clothes	$< 1.0 * 10^{9}\ \Omega$	$< 1.0 * 10^{9}\ \Omega$?	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]. The third value is the electrostatic shielding properties.
Working place surface	$> 7.5 * 10^{5}\ \Omega$ and $< 1 * 10^{9}\ \Omega$	$< 1 * 10^{6}\ \Omega$?	$1 * 10^{9}\ \Omega$ 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 v. Additionally, the discharge behavior of the surfaces have to be determined.
Decay time	< 2 s (from 1000 volt to 100 volt)	< 2 s (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 $1 * 10^{6}\ \Omega$.
Grounding[3]	$< 2\ \Omega$	?	

Notes:
[1] A new measurement method has to be developed to measure the static decay time and electrostatic shielding properties of working clothes. The existing methods are not adequate any more.
[2] The limits are required today from the IEC 61340-5-1 and ANSI/ESD S20.20-2007
[3] Metal surfaces are not approved.

Table 1. Requirements for manual working place



Picture 2 ESD required working place with a central grounding point /8/

Table 2. Requirements to ESD floors

Step	Requirements R_A		Notes
	Today	In the future	
Floor	$< 1 * 10^9\ \Omega$	$1 * 10^6 \ldots 1 * 10^7\ \Omega$	
Higher requirements	$< 3.5 * 10^7\ \Omega$	?	at a maximum electrostatic charge/voltage of 100 V
Decay time	< 2 s (from 1000 V to 100 V)	< 2 s (from 100 V to 10 V)	
ESD footwear	**?**	**?**	

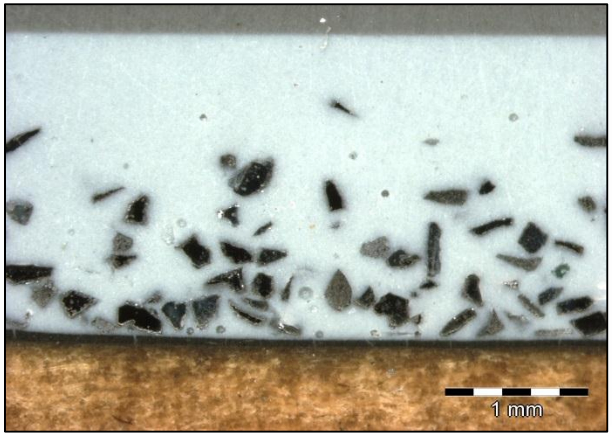
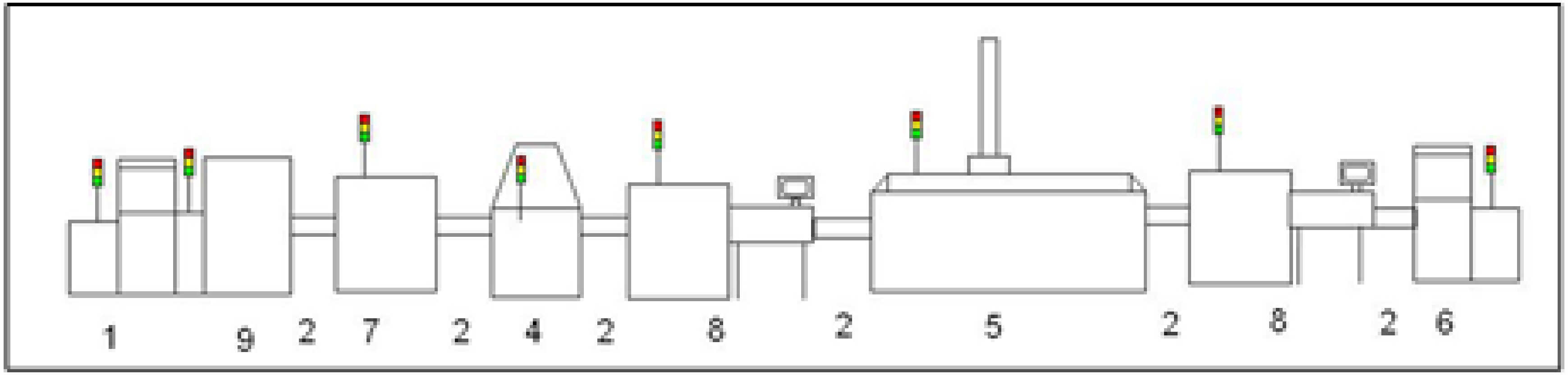
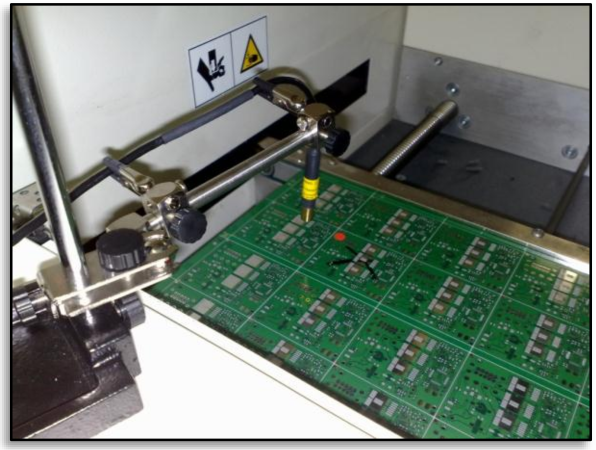


Figure. Cross section of an epoxy floor material (sample)



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 System; 9 Printer



Picture 3 SMD production line (sample)

2. Automated Handling Machines or other machines (printer, AOI, ICT, Cutting and soldering machines etc.)

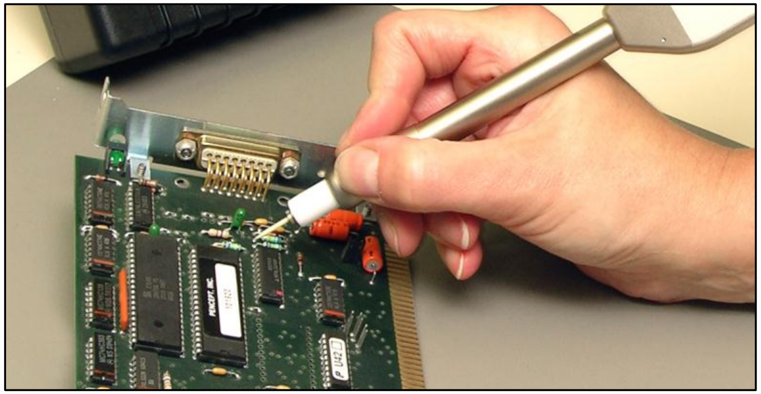
The first and only requirements are the demand for a grounding of all metal parts as well as the demand for the avoidance of plastic usage, which could generate electrostatic charges and fields. Experiences show that this is not enough for the protection of ESDS in automated machines and systems. ESDS 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 partial act. The ESDS has an isolating case, so it will be electrostatic charged during the removal out of the reel or the tray.

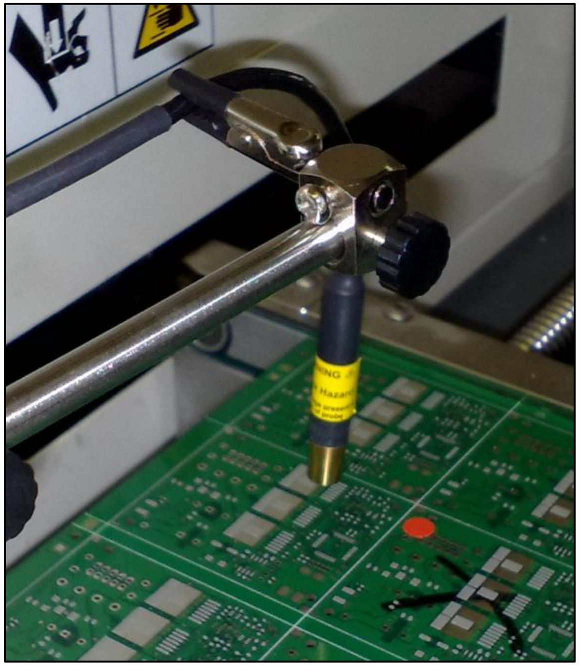
2. The electrostatic charged ESDS will be **transported to the PCB**. Thereby a further electrostatic charge can develop. The **movement at high speed Pick-and-Place System** should be enough of the generation of electrostatic charges.

3. **By placing it 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.

New Measurement Methods



Picture 4
Measurement with Contact Voltmeter CVM direct „Electrostatics charge“ on PCB without discharge and damage of IC



Picture 5
Measurement with Field electrode and EVM Electrostatics charge on PCB

New Measurement Methods

In principle, all materials must be tested whether they meet the requirements of IEC 61340-5-1 or ANSI/ESD S20.20-2007.

ESD workstations etc. must be checked according to the requirements of the ESD control programs.

The most meters on the market for the measurement of **electrostatic voltage**, **electrostatic charge** or **resistance** are not suitable for accurate measurements.

Table 3 Requirements for AHE (automated handling equipments) /5/

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

Steps for the "Machine ESD control program"

“Machine ESD control program”

1. **Analysis of the SMT production line, the individual steps and the process flow**

2. **Analysis of the used components regarding their ESD sensitivity**

3. A**nalysis of the machine, where static discharges can occur?**

4. **Performing measurements in the production line at specific steps / equipment**

5. **Creating the concept for the machine / plant**

6. **Measurements for acceptance, certification**

Steps for the “Machine ESD control program”

There are some main ESD control principles which are important in ESD Protected Area (EPA) as well as in automated process equipment:

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

Roadmaps – Solutions to 2025/2030

Year	**2000**	**2004**	**2009**	**2012**	**2015**	**2020**	**2026**	**2030**
Electrostatic Field (V/cm)[1]	200	100	55	38	28	20	10	-
Electrostatic Field (V/m)[1]	-	-	-	-	-	-	1000	< 500
Electrostatic Charge (nC)	2,5	1	0,25	0,125	0,1	0,08	0,04	< 0,04
Sizes (of Gateoxid) (nm)	180	90	50	32	25	14	11	< 10

Notes:
[1] The electrostatic field will be shown from 2026 in V/m. The correlation factor is 100.

Table 4 Development of the Sensibility of ESDS, Roadmap of ITRS /1/

ESD Association Roadmap and Roadmap form the Industry Council

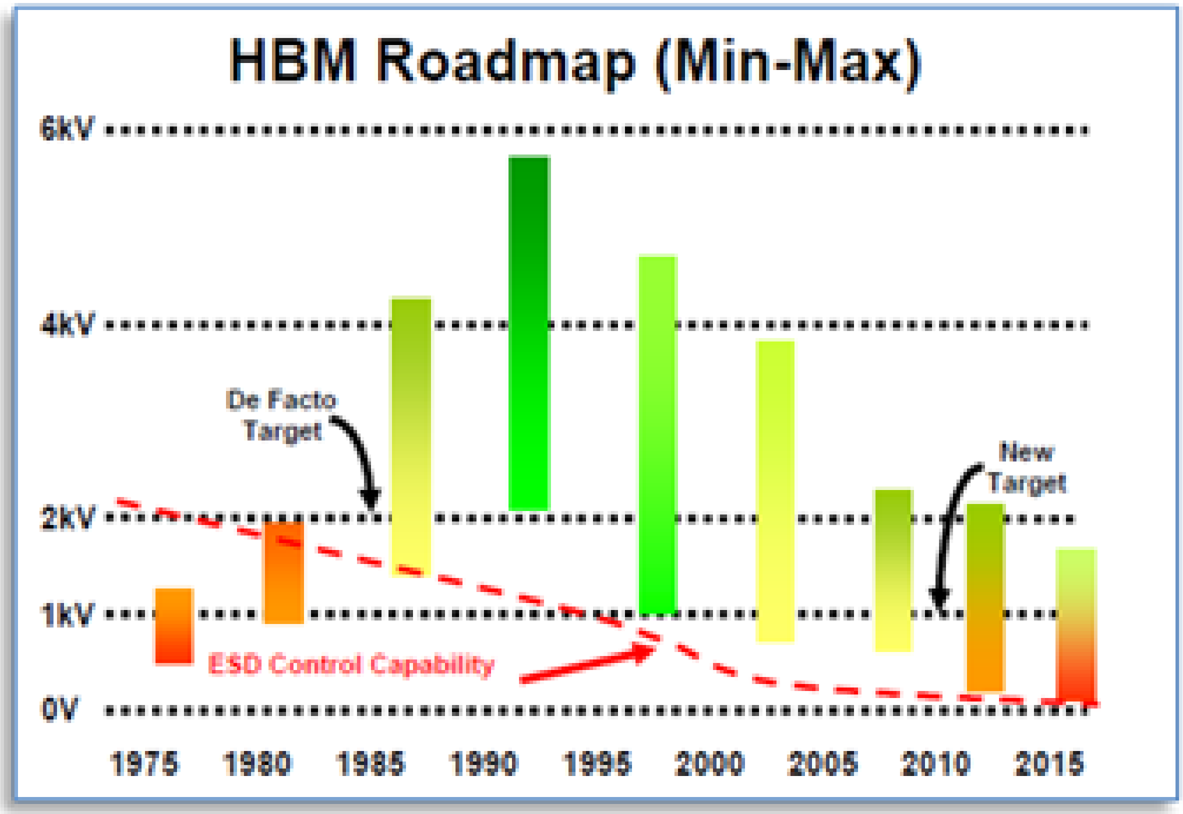


Figure 6 Human Body Model Sensitivity Limits Projections /2/

ESD Association Roadmap and Roadmap form the Industry Council

HBM Level[1]	Classification	Comments
2 kV	Exceeds requirement	With basic ESD control methods
1 kV	Meets requirement, with margin	
500 V	Adequately meets requirement	
100 V – < 500 V	Sensitive ESDS	Requires advanced ESD control methods[2]

Notes:
[1] The proposed HBM levels fully ensure that more than sufficient MM robustness (> 30 V) is also maintained with basic ESD control methods.
[2] Advanced ESD control methods are ANSI/ESD S20.20 and/or IEC 61340-5-1

Table 1: Summary of ESD HBM classification

ESD Association Roadmap and Roadmap form the Industry Council

HBM modell	**Limits**	**Notes**
ITRS roadmap	28 V/cm (2015)	Edition 2012; no special limit for each model
ESDA	2 kV, 1 kV, 500 V	
Inductry Council	1 kV, 500 V (100 V - 500 V)	

Table 2: Comparison of the limits for HBM models

ESD Association Roadmap and Roadmap form the Industry Council

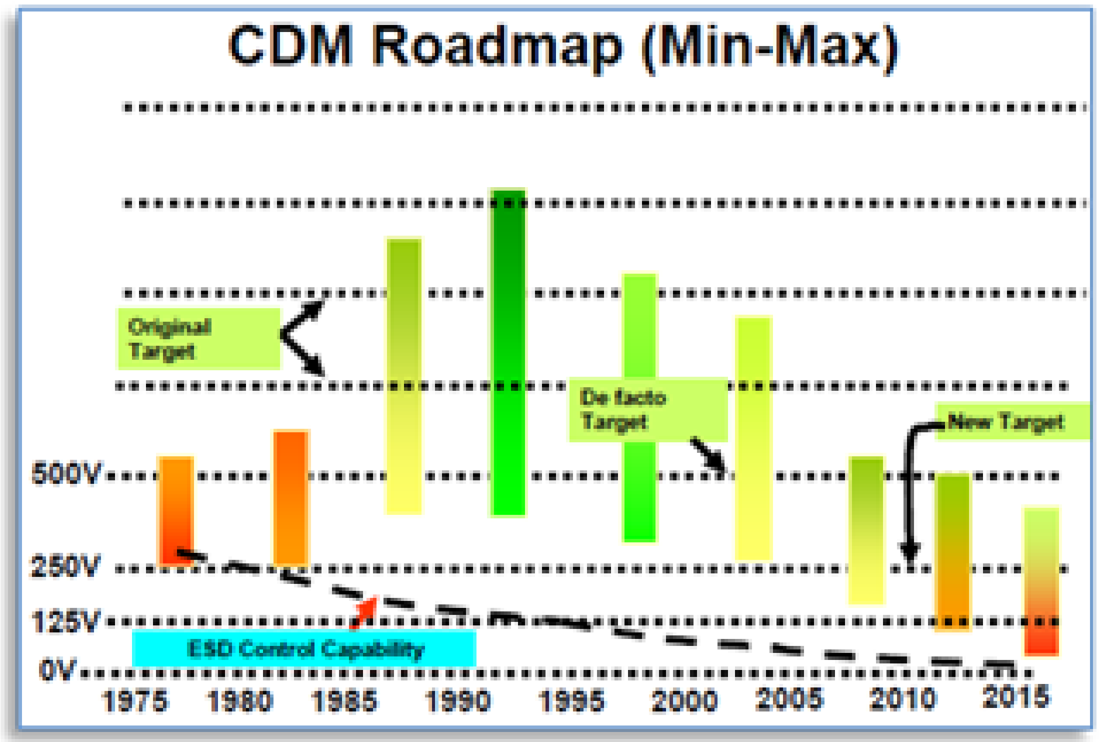


Figure 7 Charged Device Model Sensitivity Limit Projections /5/

ESD Association Roadmap and Roadmap form the Industry Council

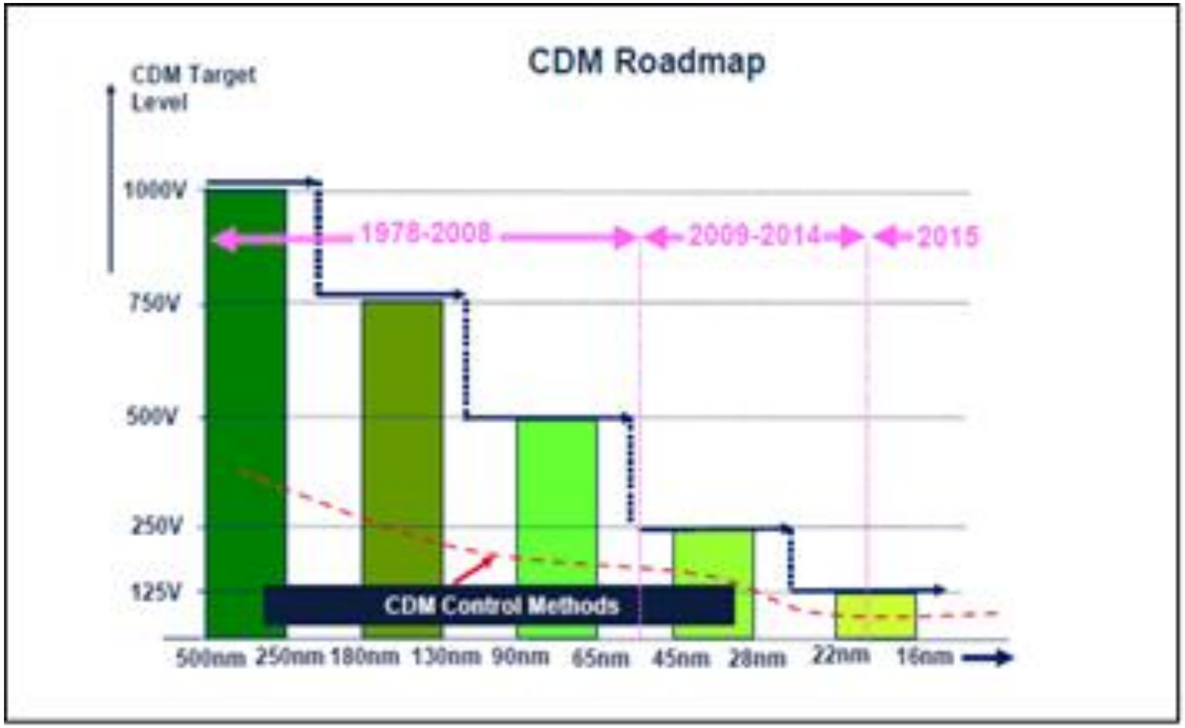


Figure 8 Technology scaling effects on practical CDM levels and the associated CDM control requirements /5/

Table II: New Recommended CDM Classification Based on Factory CDM Control

CDM classification level (tested acc. to JEDEC)	ESD control requirements
$V_{CDM} \geq 250V$	• **Basic ESD control methods** with grounding of metallic machine parts and control of insulators
$125V \leq V_{CDM} < 250V$	• **Basic ESD control methods** with grounding of metallic machine parts and control of insulators + • **Process specific measures** to reduce the charging of the device **OR** to avoid a hard discharge (high resistive material in contact with the device leads).
$V_{CDM} < 125V$	• **Basic ESD control methods** with grounding of metallic machine parts and control of insulators + • **Process specific measures** to reduce the charging of the device **AND** to avoid a hard discharge (high resistive material in contact with the device leads) + • **Charging/discharging measurements at each process step.**

Requirements for humidity and temperature

All processes and measurements depend from the actual **humidity** and **temperature**. It's important, that the values will be registries every time of measurements. Otherwise 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.

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.

ESD control program

The introduction and the control of these 5 steps were already described last year in the concept "5 Steps Plan of an ESD Control System" /10/. 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.

Conclusion

The statements are intended to highlight the problems in an EPA and the handling of electronic components in the coming years. **The components become more and more sensitive to electrostatic charges and fields**. However, the **current ESD measures are not sufficient**, and thus they are not able to protect the ESDS in the coming years.

Many companies have already installed ESD Control Systems and ESD equipment. But this will not suffice, because the plans must be constantly reviewed and adapted to the current ESD requirements. **Nevertheless, the ESD equipment on the market will no longer meet the ESD requirements in the coming years**. The must be developed. Further on, the failure models are constantly changing. So far, the HBM was the most important one, but the **CDM** becomes also more and more important.

The actual sources of static electricity are another problem. People and work places are well controlled, but the **machinery, equipment, etc. are the next generation of electrostatic charges**. The existing measurement systems are partially sufficient for the verification of persons and work places. But they are no longer sufficient to **determine the electrostatic charges and fields in very fast processes of plants and machinery**. The question is, do we still measure **static** or would a **dynamic** measurement better? At what speeds, frequencies, sampling rates, etc., should we measure?

Even conventional measurement technology is no longer sufficient today to measure electrostatic charging and discharging. Sometimes there are new materials that cannot be assessed according to the methods of resistance, such as conductive and dissipative plastic coatings.

THANK YOU