

ANSI/ESD SP17.1-2020

ESD Association Standard Practice

ANSI/ESD SP17.1-2020



*For the Protection of Electrostatic
Discharge Susceptible Items –*

Process Assessment Techniques

*Electrostatic Discharge Association
7900 Turin Rd., Bldg. 3
Rome, NY 13440*

*An American National Standard
Approved December 15, 2020*

***ESD Association Standard Practice for
the Protection of Electrostatic Discharge
Susceptible Items –
Process Assessment Techniques***

Approved November 17, 2020
EOS/ESD Association, Inc.



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FOREWORD

This standard practice¹ describes a set of methodologies, techniques, and tools that can be used to characterize a process where ESD sensitive (ESDS) items are handled. This document's procedures are meant to be used by those possessing knowledge and experience with electrostatic measurements.

This document provides methods to determine the level of ESD risk that remains in the process after ESD protective equipment and materials are implemented.

These test methods' objective is to identify if potentially damaging ESD events are occurring or if significant electrostatic charges are generated on people, equipment, materials, components, or printed circuit board assemblies (PCBA) even though there are static control measures in place.

Sensitivities of items are characterized by industry-standard ESD testing and rated by their withstand voltages. This document is intended to provide methods to determine whether items of a given withstand voltage are at risk in the process.

The wide variety of ESD protective equipment and materials and the environment in which these items are used may require test setups different from those described in this document. Users of this standard practice may need to adapt the test procedure and setups described in Annex A to produce meaningful data for the user's application.

Organizations performing these tests will need to determine if on-going process characterization is necessary, and if so, the time interval between observations. It may also be important to make these observations when new products are introduced or when process changes occur. Examples of process changes may include tools, fixtures, equipment, new items/products, and additional manufacturing steps.

The topics below are not addressed in this document:

- Program Management: see ANSI/ESD S20.20 Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)
- Compliance Verification: see ESD TR53-01 Compliance Verification of ESD Protective Equipment and Materials
- Troubleshooting: ESD TR53-01
- ESD Program Certification: see ANSI/ESD S20.20 Certification Program at www.esda.org

This document was designated ANSI/ESD SP17.1-2020 and approved on November 17, 2020.

¹ **ESD Association Standard Practice:** A procedure for performing one or more operations or functions that may or may not yield a test result. Note, if a test result is obtained it may not be reproducible.

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ESD Association Standard Practice for the Protection of Electrostatic Discharge Susceptible Items – Process Assessment Techniques**1.0 PURPOSE, SCOPE, LIMITATION, AND EXPERIENCE LEVEL REQUIRED****1.1 Purpose**

The purpose of this document is to describe a set of methodologies, techniques, and tools that can be used to characterize a process where ESD sensitive (ESDS) items are handled. The process assessment covers risks by charged personnel, ungrounded conductors, charged ESDS items, and ESDS items in an electrostatic field.

1.2 Scope

This document applies to activities that manufacture, process, assemble, install, package, label, service, test, inspect, transport, or otherwise handle electrical or electronic parts, assemblies, and equipment susceptible to damage by electrostatic discharges. This document does not apply to electrically initiated explosive items, flammable liquids, or powders. The document does not address program management, compliance verification, troubleshooting, or program manager/coordinator certification. In this version of the document, risks due to electromagnetic sources that produce AC fields are not considered.

1.3 Limitation

No detailed description of the processes and measurement techniques is given. An example of a simple risk assessment of a discharge from a charged human body is described in Annex D.

Due to the sampling nature in this document's procedures, deficiencies may exist that are not detected at the time the measurements are made. The measurements described are valid only at the time the measurements are made and may or may not change with time.

NOTE: Environmental parameters such as temperature and relative humidity (RH) may significantly impact the measurement results.

1.4 Experience Level Required

The procedures in this document are for use by personnel possessing advanced knowledge and experience with electrostatic measurements. The interpretation of the results from the measurements described in this document requires significant experience and knowledge of the physics of ESD and the process.

2.0 REFERENCED PUBLICATIONS

Unless otherwise specified, the following documents of the latest issue, revision, or amendment form a part of this standard to the extent specified herein:

ESD ADV1.0, ESD Association Glossary of Terms²

ANSI/ESD S20.20, For the Development of an Electrostatic Discharge Control Program for – Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)²

IEC61340-5-1, Electrostatics–Part 5-1: Protection of Electronic Devices from Electrostatic Phenomena – General Requirements³

² EOS/ESD Association, Inc. 7900 Turin Road, Bldg. 3, Rome, NY 13440, Ph: 315-339-6937; www.esda.org

³ IEC – International Electrotechnical Commission, www.iec.ch

3.0 DEFINITIONS

The terms used in the body of this document are in accordance with the definitions found in ESD ADV1.0, ESD Association's Glossary of Terms available for complimentary download at www.esda.org.

process. A unique combination of tools, materials, methods, and people engaged in producing a measurable output.

NOTE: The term "process" can refer to a complete assembly process or a minor step, such as a pick-and-place process.

process assessment. A methodological framework to evaluate the process capabilities regarding defined parameters.

process capability. Parameters for different ESD risks that allow safe handling of items with a given ESD withstand voltage.

4.0 PERSONNEL SAFETY

THE PROCEDURES AND EQUIPMENT DESCRIBED IN THIS DOCUMENT MAY EXPOSE PERSONNEL TO HAZARDOUS ELECTRICAL CONDITIONS. USERS OF THIS DOCUMENT ARE RESPONSIBLE FOR SELECTING EQUIPMENT THAT COMPLIES WITH APPLICABLE LAWS, REGULATORY CODES, AND BOTH EXTERNAL AND INTERNAL POLICY. USERS ARE CAUTIONED THAT THIS DOCUMENT CANNOT REPLACE OR SUPERSEDE ANY REQUIREMENTS FOR PERSONNEL SAFETY.

GROUND FAULT CIRCUIT INTERRUPTERS (GFCI) AND OTHER SAFETY PROTECTION SHOULD BE CONSIDERED WHEREVER PERSONNEL MIGHT COME INTO CONTACT WITH ELECTRICAL SOURCES.

ELECTRICAL HAZARD REDUCTION PRACTICES SHOULD BE EXERCISED, AND PROPER GROUNDING INSTRUCTIONS FOR EQUIPMENT MUST BE FOLLOWED.

THE RESISTANCE MEASUREMENTS OBTAINED THROUGH THE USE OF THIS TEST METHOD SHALL NOT BE USED TO DETERMINE THE RELATIVE SAFETY OF PERSONNEL EXPOSED TO HIGH AC OR DC VOLTAGES.

5.0 MEASUREMENT TECHNIQUES FOR ESD RISK ASSESSMENT

Specific test equipment is needed for specific measurement techniques to perform a proper risk assessment. The appropriate instruments are required to measure if a material fulfills given requirements. Additionally, the charging status of an object or even the discharge current waveform of this object must be measured. Each process step might need a different technique and tool to measure whether there is a risk to the ESDS items being processed. This chapter describes the basic measurement techniques that can be used to assess various risks in different scenarios.

Table 1 lists tools that can measure parameters to assess whether there is a risk for the items handled in a process. Measurement of the object's actual discharge under consideration is desirable but difficult to accomplish in a production environment. The discharge waveform then could be compared with the qualification waveform, and the risk could easily be assessed. However, this is often difficult to achieve, especially in a production environment. Therefore, indirect parameters must be assessed, such as charging of the object, although this parameter does not tell the user whether a catastrophic discharge is happening. If it is not possible to measure charging, measurements such as resistance to ground may need to be used (see Figure 1). A detailed description of all the test methods is given in Annex A.

NOTE: All measurements should be performed with verified test equipment to ensure that the measurements are not influenced by defective equipment.

Table 1. Overview of Possible Measurement Equipment Used for Different Scenarios to Assess ESD Risk

Parameter (Document)	Personnel	Conductors	Insulators	Devices/PCBs
Grounding (Annex A.2)	Resistance measurement apparatus	Multimeter	–	–
Electrostatic fields (Annex A.3)	Field meter	Field meter	Field meter	Field meter
Charge (Annex A.4)	Electrometer Current probe	Faraday cup Electrometer Current probe	Faraday cup	Faraday cup Electrometer Current probe
Electrostatic voltage (Annex A.5)	Charged Plate Monitor Walking Test Kit ESVM ^a HIDVM ^b Field meter ^c	ESVM ^a HIDVM ^b Field meter ^c	ESVM ^a Field meter ^c	ESVM ^a HIDVM ^b Field meter ^c
Resistance of material contacting ESDS item (Annex A.6)	Resistance measurement apparatus	Resistance measurement apparatus, Multimeter	–	Resistance measurement apparatus
Discharge events (Annex A.7)	Antenna with oscilloscope ESD event detector	Antenna with oscilloscope ESD event detector	–	Antenna with oscilloscope ESD event detector
Discharge currents (Annex A.8)	Current probe Pellegrini target	Current probe Pellegrini target CDM test head	–	Current probe CDM test head

^a ESVM = non-contact electrostatic voltmeter^b HIDVM = contact-based high-impedance digital voltmeter^c used as non-contact electrostatic voltmeter

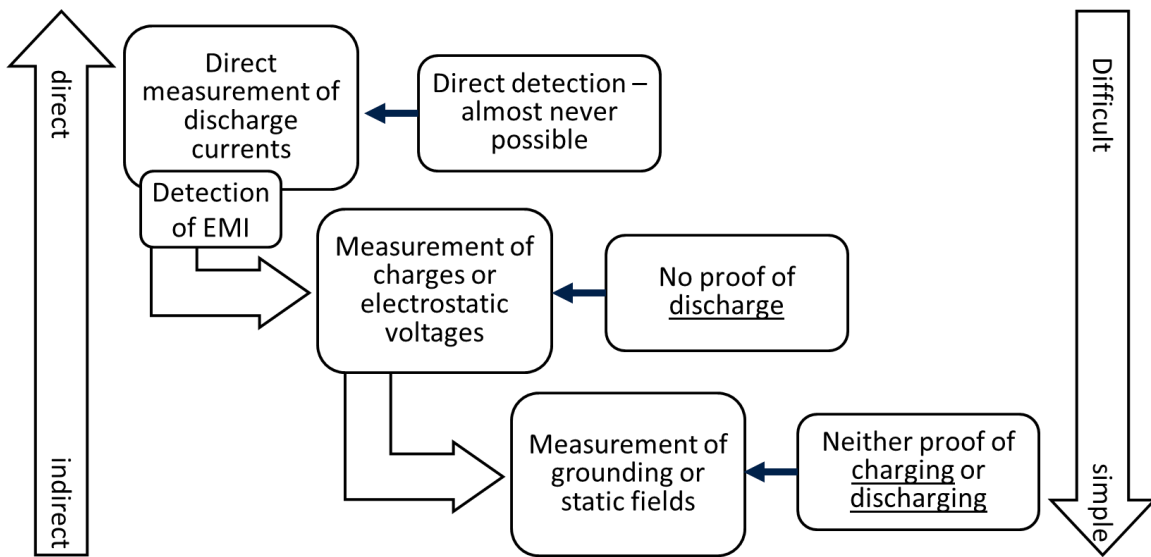


Figure 1: Direct (Best Correlation) and Indirect (Least Correlation) Measurements to Assess an ESD Risk

6.0 ESD ROBUSTNESS OF ESDS ITEMS USED IN PROCESSES

For a successful process assessment, one or more of the electrical/physical parameters listed in Table 1 and the process assessment flows in Section 7.0 must be measured and compared against set limits. However, the parameters' limits depend on the process, measurement methodologies and techniques, and ESD robustness of the ESDS items. Therefore, it is not possible to define one limit for the parameters of all ESDS items and processes. It is particularly important to distinguish between handling a single integrated circuit (IC) and electronic assemblies. For example, a single device with relatively high robustness against a charged device model (CDM) discharge may be more susceptible to damage once installed on a PCBA. The PCBA has a larger capacitance than the single device, which may result in more severe stress (higher peak current, higher charge).

Defining limits requires some knowledge about the ESD robustness of the ESDS item that is being handled in the process and knowledge about the process itself. As the ESD robustness of the ESDS item in this process is better known, and the process is analyzed in greater detail, more accurate limits can be determined. Otherwise, reasonable assumptions must be made.

The discharge event is the most critical point of a process or application, and determining the discharge current is the most direct parameter for the risk assessment. Comparing the discharge current as measured in the process with the withstand current obtained during ESD qualification tests is theoretically the best approach. However, discharge currents from qualification data are often unknown and not easily obtainable directly in process measurements. Hence, more indirect parameters must be used for ESD risk assessment. In most cases, the charging and the ESD robustness voltage of the ESDS item are used for the assessment. Each uncertainty in the ESD robustness of the ESDS item or the knowledge about the process reduces the accuracy and, consequently, results in a higher effort combined with a possible larger margin that has to be taken to exclude any risk.

Section 6.1 discusses how the withstand current of the different discharge scenarios can be either derived from qualification data or from limits defined in ANSI/ESD S20.20 or IEC 61340-5-1. A similar discussion of withstand currents of electronic assemblies is outlined in Section 6.2. These withstand currents are the basis for assessing the limits of the measurement parameters listed in Table 1 and the process assessment flows in Section 7.0.

6.1 ESD Withstand Currents of Single Devices (Components)

6.1.1 Human Body Model

Component manufacturers use the human body model (HBM) test to determine ESDS items' sensitivity to discharge from a simulated charged person. Current HBM qualification procedure is described in the standard ANSI/ESDA/JEDEC JS-001 [1]. Typically, in HBM qualification, the HBM discharge voltage V_{HBM} is reported, not the HBM discharge current I_{HBM} , which is the real damaging parameter. However, the HBM withstand current I_{HBM} can be derived from the HBM withstand voltage rather accurately by $I_{HBM} = V_{HBM}/R_{HBM}$ with $R_{HBM} = 1500$ ohms being the serial resistance in the HBM discharge network.

- If the HBM robustness in terms of withstand voltage V_{HBM} of the component is known, the withstand current can be calculated by $I_{HBM} = V_{HBM}/R_{HBM}$. For example, a component with an HBM robustness of 1000 volts has an HBM withstand current of $I_{HBM} = 1000 \text{ volts}/1500 \text{ ohms} \approx 670$ milliamperes.

NOTE: If the HBM robustness of the component is unknown, but similar products with the same power supply concept and set of I/O cells have been qualified according to HBM, this qualification value can be used as HBM robustness.

- If the HBM robustness of the component is not known, 100 volts HBM robustness can be used as a reasonable lower limit of ESDS items that can be handled in an EPA according to ANSI/ESD S20.20. For most of the components, this value might be quite conservative, but still can be achieved rather easily in a process. The maximum HBM withstand current I_{HBM} is then 67 milliamperes.
- If the component's HBM robustness is unknown, and the application does not tolerate any ESD-related failures, the assumed HBM robustness could be lowered; however, a lower HBM robustness might require additional ESD control measures.

6.1.2 Discharge of Charged Conductors

The risk of a component being damaged by the contact to a charged conductor while at least one pin of the component is on a different potential (typically grounded) was previously thought to correlate to the "machine model" (MM) test. However, MM is no longer used for component ESD qualification due to severe deficiencies in repeatability and reproducibility. Therefore, MM qualification results are typically not available.

NOTE: A discharge of a charged conductor to a floating device is modeled by CDM because it is the closest approximation.

- If HBM qualification is available, HBM thresholds divided by ten could act as a reasonable approach to correlate with a charged conductor's discharge into a component on a different potential. According to [2], the correlation between V_{HBM} and V_{MM} is in the range of 3:1 to 30:1. According to [3], the MM withstand current is 1.75 amperes per 100 volts. As an example, if the HBM robustness of a component is 500 volts, the corresponding MM withstand voltage can be estimated to be $V_{MM} = V_{HBM}/10 = 50$ volts, and the MM withstand current to be $I_{MM} = 1.75 \text{ amperes} \times (V_{MM}/100 \text{ volts}) = 880$ milliamperes.
- If the HBM robustness of the component is not known, 35 volts MM robustness against a discharge of a charged conductor can be used as a reasonable lower limit of ESDS items that can be handled in an EPA according to ANSI/ESD S20.20. For most of the components, this value might be quite conservative, but still can be achieved rather easily in a process. A withstand voltage of 35 volts corresponds to approximately 600 milliamperes MM withstand current.
- If the component's HBM robustness is unknown, and the application does not tolerate any ESD-related failures, the assumed MM robustness could be lowered; however, a lower MM robustness might require additional ESD control measures.

6.1.3 Charged Device Model

The phenomenon of a charged component or a component in the presence of an electric field being discharged when contacted by a conductive item is referred to as a charged device model event. The current version of this model is described in the standard ANSI/ESDA/JEDEC JS-002 [4]. For assessing the risk of damage in this CDM scenario, the CDM robustness of the component must be known.

- If the CDM robustness in terms of withstand current I_{CDM} of the component is known, the withstand current can be used and correlated directly to the discharge current in the process. For example, if the qualification withstand current I_{CDM} of the IC is 3.0 amperes, discharge currents of 3.0 amperes in the process should not damage the component.
- If only the CDM withstand voltage V_{CDM} is known, the CDM withstand current I_{CDM} must be estimated. For components with small capacitance (< 10 pF), the CDM current correlates to the CDM voltage with ~ 1.0 ampere/100 volts, which means $I_{CDM} = 1.0 \text{ ampere} \times (V_{CDM}/100 \text{ volts})$, knowing that this is extremely conservative for very small components. For example, for components with larger capacitance (~ 50 pF), the correlation is $I_{CDM}/V_{CDM} = 2.0 \text{ amperes}/100 \text{ volts}$, that means $I_{CDM} = 2.0 \text{ ampere} \times (V_{CDM}/100 \text{ volts})$. The capacitance of the component in the CDM tester can be approximated from a comparison with the size of the modules used for the verification of CDM qualification testers.

NOTE: If the component's CDM robustness is unknown, but similar components with the same power supply concept, set of I/O cells, and the same die size and package have been qualified according to CDM, this qualification value can be used as a realistic approximation of the CDM robustness.

- If the CDM robustness of the component is not known, 200 volts CDM robustness (corresponds to 2.0–4.0 amperes CDM current) can be used as a reasonable lower limit of ESDS items that can be handled in an EPA according to ANSI/ESD S20.20. Experience has shown that a 100-volt CDM robustness (corresponding to 1.0–2.0 amperes CDM current) is sufficient to handle components in most of the processes without ESD damage; however, it requires advanced charge and discharge control techniques in the process.

6.2 ESD Withstand Currents of Electronic Assemblies

6.2.1 Discharge of Charged Personnel

For electronic assemblies/systems, in most cases, no HBM qualification is performed. However, as the current and energy of an HBM event do not change whether discharged to a single device (component) or an electronic assembly, the worst-case approximation is that all the discharge current is dissipated through one component. The robustness of the entire system is then determined by the component with the lowest HBM robustness.

For the HBM robustness of the single component, the same considerations as in Section 6.1.1 apply.

6.2.2 Discharge of Charged Conductors

For risks of electronic assemblies by charged conductors, the same considerations are valid as for HBM risk of electronic assemblies (Section 6.2.1). As the discharge current and energy of a charged conductor does not change whether discharged to a component or an electronic assembly, the worst-case approximation is that all the discharge current is dissipated through one component. The robustness of the entire system is then determined by the component with the lowest HBM robustness.

For the robustness of the single component, the same considerations as in Section 6.1.2 apply.

NOTE: Charged cables and the risk of a cable discharge event (CDE) can also be assessed as charged isolated conductors.

6.2.3 Discharge of Boards/Systems

The worst-case HBM risk for electronic systems could be correlated to the component's HBM robustness. In contrast, for the discharge of a charged board (charged board event, CBE) or system or a board/system in an electric field, no easy correlation to any component robustness qualification exists. The reason for this is that even if on a board, a component pin is contacted directly, the charge stored at the board is typically significantly higher compared to the charge stored on a single component. Knowing the discharge peak current is required to establish any worst-case approximation. No qualification method exists yet for boards and electronic assemblies.

As a very simple worst-case approximation, the maximum allowed peak discharge current of a board (that is, the current flowing through the conductive item that contacts the board) can be estimated from the component's CDM threshold currents, see Section 6.1.3. As the charge stored at the board is larger than the charge stored on a single component, resulting in a wider full-width half maximum of the discharge current waveform and consequently more severe stress, a safety factor should be included. From experimental data, a safety factor of two seems to be a reasonable estimate [5]. For example, if all components on the board or in the system do not fail 3 amperes CDM current, very likely, a board discharge current of 1.5 amperes will not cause damage to the components on the board. This worst-case approximation requires that the discharge current in the process can be measured, which is rarely the case.

If the discharge current of the board cannot be measured, the only reasonable approach is to avoid "all" possible discharges or limit the charging of the board/system to an exceptionally low and safe value. From data in the literature (for example, see [13] and references therein), a worst-case approximation could be to limit the charging of the board/system to one-tenth of the minimum CDM robustness of all devices. For example, if the minimum CDM robustness of all components is known or assumed to be 200 volts, then the charging of the board should not exceed 20 volts.

NOTE: Another option is to limit the discharge current by contacting the ESDS item with a dissipative or insulative material. See the assessment flows in Sections 7.4 and 7.5.

7.0 PROCESS ASSESSMENT FLOW

7.1 General Considerations

Standards such as ANSI/ESD S20.20 and IEC 61340-5-1 give guidance on implementing an ESD control program for handling ESDS items in EPAs. ESD failures can still happen even in well-equipped EPAs, as reported in many publications (see references in [6]). A detailed risk assessment is needed for the various process steps to avoid failures coming from the production process. A process assessment needs to cover risks induced by charged personnel, ungrounded conductors, charged insulators, and charged ESDS items.

Although automated processes dominate many production areas, manual process steps still exist, especially at process transition points and manual PCBA handling processes. Therefore, assessing operator grounding and charging of personnel is necessary. Standards such as ANSI/ESD STM97.2 [7] provide good guidance on measuring an operator's body voltage using footwear/flooring grounding. Without such an assessment, ESD protective elements might not fit together and are not as effective.

Isolated conductors can charge and discharge into ESDS items. Hence, it is also important to care for isolated conductors when handling ESDS items. These failures can be avoided by removing charges from all conductors, especially those in direct or close contact with the ESDS item. Following ANSI/ESD S20.20, the maximum voltage difference between an ESDS item and a conductor shall not exceed 35 volts to limit possible discharge currents between the conductor and the ESDS item to an acceptable level.

Issues with CDM-type discharges are becoming more and more dominant. Many handling steps are now almost completely automated without interaction from people. A fact that imposes a high risk here is that many processes use insulators to aid in the process of producing a product or are part of the product itself. One basic idea of CDM protection is to control the charge on insulators, thereby avoiding charging and electrostatic fields wherever possible. This can be achieved by removing all nonessential insulators and controlling/reducing the charging of process required

insulators to a safe level – including charging of both devices and printed circuit board assemblies (PCBAs).

The following sections describe this in more detail.

7.2 Manual Handling Steps

7.2.1 Introduction

Like automated systems, manual handling steps must be checked for charge generation and the potential for direct discharge paths into ESDS items. According to ANSI/ESD S20.20, the charging is limited to an electrostatic voltage of 100 volts on the personnel in an EPA. Whether this value or any other value obtained in the process can cause damage to an ESDS item handled by the personnel has to be evaluated.

The time to complete the steps being evaluated must be considered during the evaluation. If the evaluation is slower than the process, potential critical discharging or charging could be missed.

7.2.2 Parameter Limits for ESD Process Assessment in Manual Handling Steps

Four different parameters can be measured to assess the risk of an ESDS item damaged by charged personnel. The results of the measurements can vary depending on the personnel and the grounding mechanisms. This variation must be considered in the assessment.

1. Discharge current (time-dependent). The discharge peak current of charged personnel into ground can be related directly to the HBM withstand current of an ESDS item (see Sections 6.1.1 and 6.2.1). For a correlation, the decay time of the measured pulse must be below 170 ns. The decay time is the time interval between when the current is at maximum and when the pulse current is decayed to 36.8% of the maximum. Typically, the HBM stress in a commercial HBM qualification tester is much more severe than the discharge of a human being charged to the same voltage [8] and does not need any additional margin. Therefore, the HBM withstand current I_{HBM} can be an approximation of the upper limit for the personnel's discharge peak current. For example, an IC with a component HBM current threshold $I_{\text{HBM}} = 1$ ampere should not be damaged by a discharge current of 1 ampere from personnel (or according to Section 6.1.1, by a discharge current of personnel charged to 1500 volts).
2. Contact resistance of personnel. With a measured contact resistance of personnel R_{contact} , the maximum discharge current of charged personnel $I_{\text{personnel}} = V_{\text{personnel}}/R_{\text{contact}}$ can be derived by Ohm's law and compared with the component HBM qualification withstand current I_{HBM} . For this, a worst-case maximum electrostatic potential of the personnel (that is, the personnel's charging) must be known. If the personnel work in an ANSI/ESD S20.20-compliant ESD protected area, the maximum charging of personnel is limited to 100 volts. For example, with HBM qualification withstand current $I_{\text{HBM}} = 1$ ampere, the minimum contact resistance of personnel R_{contact} can be calculated by $R_{\text{contact}} = 100 \text{ volts}/1 \text{ ampere} = 100 \text{ ohms}$. In contrast, if the personnel are working outside an EPA and can consequently be charged to voltages as high as 30,000 volts, the minimum resistance is higher, $R_{\text{contact}} = 30,000 \text{ volts}/1 \text{ ampere} = 30 \text{ kilohms}$.
3. Electrostatic voltage of personnel. Quite often, the electrostatic voltage of personnel can be measured rather easily, and it is simply compared with the HBM withstand voltage V_{HBM} of the ESDS item. This works well as a worst-case approximation, as the HBM stress in a commercial HBM qualification tester is, in general, more severe than the discharge of a human being charged to the same voltage [8]. However, this approximation does not consider possible serial resistances in the discharge path from the personnel to the ESDS item (see above), limiting the personnel's discharge current. For example, a component with an HBM robustness of $V_{\text{HBM}} = 1500$ volts should not be damaged by a discharge of personnel charged to 1500 volts. However, if the personnel wears gloves with, for example, $R_{\text{contact}} = 100$ megohms which do not break down at high voltages, there is no risk of a critical discharge even for electrostatic voltages of personnel far beyond $V_{\text{HBM}} = 1500$ volts, which is not considered in the simple assessment based on electrostatic voltages.