Recommendations for the use and test of ESD protective garments in electronics industry

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1 Introduction

Electric charges on the clothing of operators are typically accumulated when the operator is moving around, i.e., by triboelectric effects (rubbing or separation of two materials). In electronics manufacturing environment specially designed protective clothing is often used to minimise accumulation and retention of the charge. This clothing, called an ESD garment, is worn over the ordinary clothing of the operator. Thus it should also provide shielding against any surface voltages or voltage transients arising from underlying garments. In some cases the ESD garments are not used just to prevent ESD damage to electronics but also to prevent the electronics from being damaged by the contamination of dust particles (cleanroom clothing).

The main purpose of ESD garments is to minimise risks of ESD failures to sensitive electronics due to charged clothing. Testing and evaluation of garments should take this into account. Present standards for the evaluation of the ESD garments protective performance [1,2] are mainly based on the results of researches performed in the 70's-80’s with garments having electrostatically homogeneous surfaces. The protective clothing was typically either a pure cotton or cotton-mixture garment which could have been topically treated by hygroscopic agents. Such garments, as well as the test methods, satisfied the requirements of that time. Since then the electronics industry demanded increasing performances from the ESD protective clothing. At the same time there has been much progress in the textile industry. As a result the ESD-garments in use today are made of composite fabrics where a grid or stripes of conductive threads are present inside a matrix of cotton, polyester or mixtures of these materials. Furthermore, the conductive threads are more and more frequently made by composites, i.e. by a mixture of conductive and insulating fibres (core conductive fibres, sandwich type fibres etc.), see Fig. 1. All the latter elements lead to very heterogeneous fabrics for garments.

While the presently available standard test methods for garments used in electronics industry [1,2] have been developed for homogeneous materials, they do not allow a proper characterisation of the modern garments performances [3-6]. Furthermore, it is not certain that they indicate how much the garments will protect the electronics from ESD. Therefore, the European Commission, in connection with the Technical Committee No 101 ”Electrostatics” of the International Electrotechnical Commission (IEC), issued a call for a research about new test methods for ESD garments which leads to the ESTAT-Garments project.

In this report the final results and conclusions of the ESTAT-Garments project are given as recommendations for the use and test of ESD protective clothing in electronics industry. The report is backed up by a three-year study. The project has resulted in lots of public intermediate or other results giving important background information for the main conclusions of the project. A reader is referred to the original reports and publications for more details [7-26] (all publications of the project are available at the project website http://estat.vtt.fi).

In Chapter 2 we give arguments why and when ESD protective garments should be used. In Chapter 3 we will define a good ESD protective garment in more detail. The ESTAT-Garments recommendations for the test of ESD protective garments in electronics industry are given in Chapter 4. Recommendations for the electrostatic performance of garments are also given in Chapter 4. Application of the ESTAT-Garments results in the electronics industry and in IEC TC101 standardisation projects are discussed in Chapter 5. While Chapters 1-4 presents the ESTAT-Garments team standpoint, Chapter 5 is a personal view of Dr. Jeremy Smallwood. The ESTAT-project team asked Dr. Smallwood to write the chapter in order to enhance the exploitation of project results into the industry and current standardisation work. Finally, conclusions are given in Chapter 6.

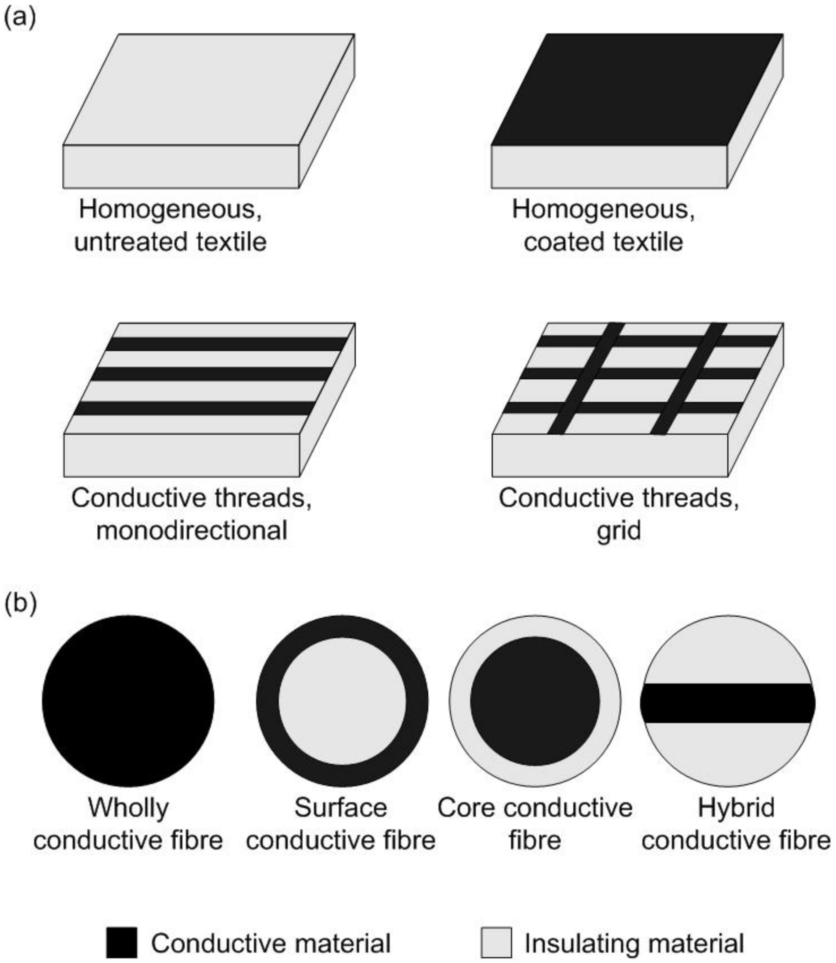

Figure 1 (a) Structures of electrostatically homogeneous and heterogeneous textiles, (b) structures of some commonly used conductive fibres.

2 Why and when ESD protective garments should be used?

The purpose of ESD protective garments is to minimise risks of ESD failures to sensitive electronics due to charged clothing. The required protection level depends on the susceptibility of the devices in production to Human Body Model (HBM) and Charged Device Model (CDM) ESD. The protective performance required from clothing depends also on the failure mechanisms of ESD sensitive devices to be protected. Most of the devices are susceptible to the energy of the discharge. Some devices are more susceptible to internal overvoltage due to ESD. Energy susceptible devices fail by the high discharge current heating a small volume of material to a failure temperature. The failure temperature is often the melting temperature of the material, but may be determined by changes in other characteristics such as magnetic properties in MR heads. In the case of discharges having long duration and significant heat transfer from the damage region, the key parameter for energy susceptible devices is the discharge power instead of discharge energy. In voltage susceptible devices, the voltage sensitive part fails when the breakdown voltage or field strength is reached. This may happen due to charge accumulation on an isolated part, or by the voltage drop due to a passing high current ESD impulse. The peak ESD current and charge are likely to be fundamentally important in both energy and voltage susceptible device damage.

An ESD failure caused by charged clothing can, in practice, happen in two different ways;

1) by discharge from a charged device,
2) by a direct discharge to a device.

The main source of ESD risk with reference to clothing may occur where ESDS can reach high induced voltage due to external fields from charged clothing, and subsequently experience a field induced CDM type discharge. A device may be charged also by accidental rubbing against the garment. The risk threshold is reached when the charge induced or generated on the device reaches the device CDM withstand voltage level. Thus from the ESD control point of view it seems reasonable to pay attention to device charging.

Also an entire Printed Wiring Board (PWB) may become charged due to charged clothing giving rise to a risk of Charged Board Model (CBM) ESD. A PWB conductor can have much higher capacitance than a single device and, thus can store much more charge than a device. Depending on the board circuit, that could mean an increased ESD risk.

ESD risks due to induction charging of ESDS or PWB assembly, and subsequent CDM ESD, are strongly influenced by electrostatic field external to garment. The electrostatic field external to garment depends on

- chargeability of outer clothing
- ability of charge dissipation of clothing
- ability of outer clothing to shield static electric field from clothing under the outer garment
- suppression of field external to the garment by coupling to grounded body or conductive threads of garment.

All the four factors are strongly dependent on the fabric material of garment, garment design, humidity, grounding of person as well as garment, etc. For example, the triboelectric chargeability of outer clothing depends strongly on the material of clothing as well as the humidity of the environment. Normal clothing with synthetic fibres, such as polyester, could be easily charged to several kV by triboelectric effects. In dry conditions of relative humidity « 50 % RH even pure cotton garments could be charged to several kV. We will come back to these questions in more detail later on in this report.

A general method used in ESD control programs [1,27] to minimise ESD risks due to induction charging of devices in EPA is to place limits for the electrostatic field at the position of ESDS [1] and to the surface potential of materials which cannot be grounded (that is insulators) [27]. The IEC 61340-5-2 says that the electrostatic field at the position of ESDS should not exceed 10 kV/m [28]. ANSI/ESD S20.20 says that all process essential insulators that have surface potential that exceed 2000 V should be kept at a minimum distance of 30 cm from ESDS items [27]. These general EPA requirements can both be applied to clothing used inside EPA. Sometimes the use of special ESD protective clothing is required to satisfy the EPA requirements.

ESD threats due to accidental rubbing of devices or PWBs by garment fabric can not be easily minimised to a satisfactory low level by a proper choice of garment fabric. One can always find such a combination, PWB assembly – fabric, where triboelectric charging is high. This type of risk for ESD failures can be minimised only by minimising occasions for the accidental rubbing by using a proper design of ESD garments: the garments should fit snugly, particularly in the sleeves. A short sleeve T-shirt would be ideal clothing from that aspect.

The second category of ESD risks with reference to clothing is related to direct discharges from charged clothing into a victim device. Direct discharges may cause damage by charge injection to the device, which could occur whether or not the device is grounded. In theory, also a charged device may be discharged to grounded conductive elements of clothing creating a risk for an ESD failure of the device. Direct discharges from charged clothing into an ESDS are related to insulating surfaces of large area (well over 20 mm x 20 mm) or improperly or completely unearthed conductive garment elements, such as conductive threads or large press studs. Garment characteristics should be chosen so that neither of these possibilities can give significant ESD damage risk. Sometimes that requires special ESD garments where conductive elements are effectively grounded. Further redundancy to ESD control is achieved when the surface resistance of conductive garment elements are in the range of electrostatic dissipative materials (from 1×10^5 Ω to 1×10^{11} Ω according to ref. [2]) and there are no continuous insulating areas in the garment exceeding the size of about 20 mm x 20 mm.

ESD failures due to the mechanisms above can be minimised by using properly designed and used ESD protective garment. It is not straightforward, however, to give strict recommendations when there is clear benefit for the use of ESD garments. It depends on the ESD susceptibility of the ESDS being handled, costs and consequences of ESD failures, etc. Furthermore, the humidity of production environment has a strong influence on the charging of clothing and, subsequently, on the need to use special ESD protective clothing. Benefits of ESD garments are not the same in dry and humid climate. As an example, in a facility with warm humid climate where operators wear short sleeve T-shirts and do not handle very ESD sensitive devices, there may not be special need for the use of ESD garments. In contrast, in a facility with dry climate, about ≤ 40 % RH, a company could benefit from using ESD garments, especially if operators could wear long sleeve clothing, because at dry conditions normal clothing will not dissipate charge sufficiently well. The studies done in the ESTAT-Garments project have shown that, independently of garment material, below 40 % RH charge on an outer garment will not migrate through undergarment to grounded operator's body sufficiently well [25].

As a rule of thumb should be given, we can say that the use of ESD protective clothing should be seriously considered;

- if the CDM withstand of devices being handled is ≤ 500 V,
- if the HBM withstand of devices being handled is ≤ 1 kV.

ESD garments should be used also when handling less susceptible devices if required due to;

- contamination control,
- costs and consequences of an ESD failure (reliability of products, etc.).

With additional rules for the EPA banning fleece and other synthetic materials in operator's clothing, the need for the use of ESD garments is moved to the handling of devices with lower ESD withstand.

Contamination prevention standpoint is another important application area for ESD garments (in addition to the ESD protection). In this application the garment (cleanroom clothing) must have electrostatic field preventative properties in order to minimise contamination by electrostatic attraction (ESA) of particles. For cleanroom clothing, chargeability of the garment fabric (surface potential) is the main electrostatic parameter to control. Other electrostatic properties important for ESD garments may be of negligible importance. That should have influence to the requirements set for ESD protective clothing used for contamination control. We will come back to this question in more detail later on in this report.

One should neither underestimate psychological effects related to ESD garments. It is a studied fact that the use of ESD garments increases general awareness of ESD control in EPA [29].

3 What is a good ESD garment?

An ESD protective garment should ideally have the following functions:

- The protective garment should effectively shield the electric field originating from the insulating parts of the operators normal clothing.
- The protective garment should prevent direct discharges from the normal clothing of the operator.
- The protective garment should not itself cause similar problems, i.e., it should not cause an electrostatic field external to the garment and it should not constitute a potential source of direct electrostatic discharges.

In practice these targets may not always be met.

Requirements for the ESD protective clothing in electronics industry are very diverse. Some manufacturers, handling very ESD sensitive devices, require high ESD protective performance for the outer garments of their production personnel, while another manufacturer would be satisfied with much lower ESD protective performance. In some cases the ESD garments also play other important roles such as protection of electronics from contamination (dust) particles originating at the operator (cleanroom clothing). Then the major electrostatic function of the garment could be to reduce electrostatic attraction (ESA) instead of minimising ESD failures. The diverse requirements for ESD garments have lead to diverse structures of the ESD garments. This makes it challenging to practically define a good ESD garment.

The studies of the ESTAT-Garments resulted in two guiding principles for the definition of a good garment: one which takes into account the risks due to electrostatic field external to charged garment (Table 1), and another which takes into account risks due to direct ESD from charged clothing (Table 2). The guiding principles in Table 1 covers both the ESD risks due to induction charging of ESDS, and subsequent CDM ESD, as well as ESA minimisation in contamination control in cleanrooms. The principles in Table 2 are solely for minimising ESD damages of ESDS. All principles given in Tables 1 and 2 are fully consistent with the general ESD control philosophy for EPA given in ESD control standards [1,27]. Depending on the protective level needed, tighter requirements than the general EPA requirements given in the tables may be preferable.

Grounding of conductive garments parts (conductive threads etc.) is mentioned only in Table 2, but effective grounding largely improves the protective performance of the garment also with respect to the electrostatic field external to the garment as well as to the surface potential of the garment. Grounded conductive threads will drain charge on the garment surface away. Electrical integrity of seams is here important, i.e., the garment should have electrical conductivity through all panels. Furthermore, grounded conductive threads provide also electrostatic shielding for the charge on under laying garments by coupling the electrostatic field to ground. A dense grid (for example, 5 mm x 5 mm, or even below) of conductive threads gives essentially better electrostatic shielding than a loose (20 mm x 20 mm) grid.

Table 1 Guiding principles of good ESD garments for the minimisation of electrostatic field external to charged garment as well as induction charging of ESDS.

- Surface potential of outer clothing shall not exceed 2 kV in any circumstance. The lower potential the better value.
- An ESDS shall not be exposed to electrostatic field exceeding 10 kV/m; due to charges on the clothing of the operator.

Table 2 Guiding principles of good ESD garments for the minimisation of direct discharges from charged clothing.

- All surface conductive parts of garment should be effectively grounded.
- Garment should not have continuous insulating areas of size exceeding 20 mm x 20 mm. If conductive threads are in a stripe form, the distance between neighbouring stripes should be less than 10 mm.

A core conductive garment cannot be adequately grounded due to the buried conductive elements and can never be considered as electrically continuous at dry conditions. We cannot, however, conclude anything from this itself about their potential value in ESD protective garments.

The grounding of an ESD garment can be accomplished by several means;

- through a conductive wrist cuff in direct contact with the skin of a grounded operator,
- through a separate ground cord directly attached to an identified point on the garment,
- through a wrist strap-direct connection with an adapter
- through contact with an ESD chair that is grounded via an ESD floor (effective for seated personnel only).

Although possible, we do not recommend the use of a garment as part of the person's primary ground path (a person is connected to a garment, which is connected to a grounding cord that is attached to ESD ground).

The design of garment has also an important influence on the ESD protective performance of the garment. Loose garments have much lower ESD protective performance than similar garments that fit snugly. Voltage suppression effect (here understood as the suppression of surface voltage on an inhabited ESD garment or on an undergarment due to coupling of fields to the grounded body of the operator) depends largely on the distance of the garment to wearer's body. If the distance is several centimetres, this suppression effect is negligible. Sleeves, in particular, are critical in this aspect, because they are very close to ESDS. Loose sleeves also increase the risk of device charging, by accidental garment contact (triboelectric charging) in between the sleeve and the ESDS.

The diverse needs for the protective performance of ESD garments have led us to propose classification of ESD garments according to the ESD protective performance they provide. Two classes of ESD garments are proposed, Table 3. Electrostatic requirements (limits of acceptance) for the Class A and Class B garments would be connected to test methods. These methods and limits will be discussed and given in the next chapter.

Table 3 ESTAT-Garment proposal for the classification of ESD garments.

Class A

- Class A garments must be grounded in use.
- Class A garments are electrically continuous, low-charging[1] and either static dissipative or conductive.
- Class A garments are recommended for the handling of very ESD sensitive devices.

Class B

- Class B garments are recommended, but not required to be grounded in use.
- Class B garments are low-charging[1], and need not have measurable electrical continuity.

[1] Low charging material is a material with low tendency for charge separation by contact or by rubbing against other materials

Note1. The person who wears the clothing must be earthed both with Class A and Class B garments.
Note 2. Class B garments are suitable for cases where the primary function of ESD garments is in the contamination control (cleanroom usage) and ESD protection is of secondary importance.
Note 3. A cleanroom garment should be of type A when high ESD protective performance is of primary priority, otherwise it can be of type B.
Note 4. The requirements and recommendations of this report may not be relevant for those cleanroom garments used outside EPA.

4 Recommendations for the test of ESD garments

4.1 Requirements for the testing of ESD garments

The diverse requirements for the ESD garments as well as the diverse structure of the garments give a great challenge for the test methods characterising the protective performance of the clothing and for the recommendations for the performance of these garments. In practice, there is a need for different types and levels of tests [4]:

1. Evaluation test(s) for new products to enter the market, which should be done in laboratories under controlled conditions.
2. Approval test(s) for first article or incoming material to determine if the measured values or other requirement specified by the inspection order are within limits.
3. Periodic field/audit test(s) done for garments already in use, which test(s) would be done in production sites or in laundries after washing.

Furthermore, while the end-users of garments are interested in garment tests, manufacturers of protective garments as well as garment fabrics do need also fabric level tests in order to be able to produce garments fulfilling the end-user needs.

Existing fabric and garment test methods were evaluated during the first half of the project. In addition to the major standard test methods, we evaluated many existing laboratory methods. Some preliminary screening of the methods was done based mainly on the experience from the past European research project SMT4-CT96-2079 “The evaluation of the electrostatic safety of personal protective clothing for use in flammable atmospheres” [5,6]. The main results of the study were reported in the public ESTAT-Garments report “Evaluation of existing test methods for ESD garments” [7].

According to the evaluation, current standard resistance based test methods for ESD garments do not characterise satisfactorily well the protective performance of modern ESD garments. They cover most of the key parameters influencing the ESD protective performance only when the garment is made of electrically homogeneous materials or has electrically homogeneous surface layer. ESD safety of garments with core conductive garments cannot be assessed at all using resistive methods.

The results launched a development work for completely new test methods as well as for the modification of a few existing standard or laboratory test methods. Finally, five garment level and four fabric level test methods were selected for the ESTAT-Garments interlaboratory (round robin) tests. The purposes of the interlaboratory tests were to evaluate the repeatability and reproducibility of results, to assess written descriptions of the test methods, and to reveal needs of further specification in those methods still under development. The results were reported in the public ESTAT-Garments report “ESTAT-Garments Interlaboratory tests” [8]. We will not repeat the results here but, instead, go directly to the final conclusions of the project based on the results of these interlaboratory tests and other studies of the project.

The main purpose of ESD protective garments is to minimise risks of ESD failures to ESDS. Any good test method for ESD garments should assess garment's ability to provide ESD protection. The following parameters have been identified in the ESTAT-Garments project as the key parameters to control in order to minimise ESD failures of ESDS with reference to garments (the parameters not being in any priority order) [7]:

- Induction charging of a device due to electric field external to the garment.
- Device charging due to accidental rubbing against the garment.
- Peak ESD current to or from a device.
- Charge transfer to or from a victim device.

Induction charging of a device due to an electrostatic field external to the garment depends on the chargeability, the electrostatic shielding property, the rate of charge dissipation of the garment/garment material and on the voltage suppression of the system. All these quantities depend on the garment fabric and on the grounding of the fabric.

Device charging due to accidental contact against the garment depends on the combination garment fabric and the material of the sensitive device itself; therefore it is not a pure garment property. It can be minimised only by minimising occasions for the rubbing using properly designed garments: the garments should fit snugly, particularly in the sleeves. This is a design issue that couples to the end users demands on the design and, therefore, not a subject of garment or fabric testing, however is of interest for qualifying the garment for use.

Peak ESD current and charge transfer in a direct ESD event depend on the fabric parameters; resistivity, amount of retained charge and voltage differences that arise. These are garment fabric and grounding issues.

Grounding of all garment panels has also a significant influence on the ESD protective performance of the garment. Garments based on core conductive fibres cannot be galvanically grounded, which does not mean that they do not provide any protection to ESDS.

The key parameters were further analysed and, as a result, a list of garment and garment material (fabric) related factors, influencing the key parameters was obtained. The list is given in Table 4 [7].

4.2 Key parameters vs. test methods

Table 4 together with Tables 1 to 3, as well as the results of the interlaboratory tests [8], form a basis for defining the necessary test methods for the assessment of garment's ability to provide good ESD protection.

In Table 4, a number of important factors are related to the concept of induction charging of, and direct discharges from / to, an ESDS. Many of these factors rely on the fact that the fabric is grounded or connected to a large capacitance. In this case, a large capacitance can be the conducting part of the fabric / garment coupled to the grounded body of the wearer of the garment (Table 3).

The difference in between a garment and a piece of fabric is in the seams. If a garment should be grounded then all panels of the garment must be electrically connected to each other. I.e. to qualify such a garment one must qualify both the fabric and its seams. If a garment should or can not be grounded then one only needs to qualify the fabric (Table 3). To check the seams of a garment and to have an overall picture of the resistivity of the garment we recommend two different methods. The standard point-to-point resistance measurement (either the IEC [1] or ESD Association [2] version) and the ESTAT-Garments test method "Measurement of the charge decay time of ESD-protective garments". All relevant fabric panels should be checked. The later is a new test method originating from the SP 2175 test method; test method description is given in Annex 1. Both these methods give information on the garments surface resistance as well as on the workmanship of the garment (electrical integrity of seams). In some situations charge decay is a better way to verify the garment performance than by a resistance measurement, because the nonlinearities in the garment electrical behaviour below the test voltages can be detected. We are therefore suggesting the ESTAT-Garments garment level charge decay test as an alternative for the point-to-point resistance measurement.

Table 4 Electrostatic factors influencing to the key parameters to control with reference to charged ESD garments and ESD garment fabrics.

1. **Device charging due to electrostatic field external to the garment** is largely determined by;

- ♦ the **chargeability** of the garment fabric, i.e. charge generation by triboelectrification,
- ♦ the **rate of charge dissipation** of the garment/garment material, which can occur through three different mechanisms;
  - conduction,
  - induction,
  - corona mechanism,
- ♦ the **electrostatic field shielding property** of the garment material (i.e. property to suppress fields due to charge on underneath normal clothing by coupling the field to grounded garment elements), which depends on
  - the resistivity of the conductive threads,
  - the resistivity of base material,
  - the grid structure,
- ♦ **voltage suppression** (here understood as the suppression of surface voltage on an inhabited ESD garment or on an undergarment due to coupling of fields to the grounded body of the operator), which depends mainly on
  - the distance of the garment to nearby conductive objects (usually earthed, e.g. the wearer's body), and
  - the area over which the charge has spread on the garment.

2. **Peak ESD current and charge transfer in a direct discharge** from charged fabric is largely determined by;

- ♦ the resistivity of conductive threads,
- ♦ the grid density and grid structure,
- ♦ the amount of retained charge,
- ♦ area of material discharged.

The ESTAT-Garments garment level charge decay test method could also provide a quick and automatic garment verification when entering EPA, similar to the automatic ESD footwear tester. It would not be difficult to construct a simple garment tester based on the method. In addition the point-to-point as well as the ESTAT-Garments charge decay test method gives indirectly information on the charge dissipation properties of the conductive parts of groundable garments. It does not, however, give information on any insulating parts of the fabric or directly relate to the external electrostatic field.

The function of the fabric itself can not be verified by the two previously mentioned methods only. Other methods need to be used to correctly verify the properties mentioned in Table 4. The following properties are mentioned; chargeability, rate of charge dissipation, electrostatic shielding and voltage suppression under point 1 and under point 2; peak current and charge transfer in ESD from the material. Many of these quantities are in some way defined by the different test methods and many of these test methods actually refer to more then one of these quantities.

The electrostatic shielding performance of ESD protective garment fabric can be defined and measured with high estimated repeatability and reproducibility by the EN 1149-3 Method 2 (induction charging) [30]. This method also gives information about the charge dissipation rate of the fabric.

Voltage suppression is not purely a fabric property, but also depends on the system; wearer and garment. It can be defined and measured with high estimated repeatability and reproducibility by the ESTAT-Garments test method "Measurement of the charge decay time of ESD-protective garments", Annex 1. One should note that the tighter the garment fits the wearer, the better is the voltage suppression.

If the garment’s ability to provide protection against direct ESD risks, i.e. limitations on the peak current and limits of the total amount of charge, is to be studied in greater detail, another new ESTAT-Garments test method "Measurement of a direct discharge from an ESD protective material, such as an ESD garment / fabric" would be a recommended choice. A new test method description of the direct ESD test is given in Annex 2. Some further specification for the method has been done since the ESTAT-Garments interlaboratory tests in order to improve the reproducibility of results. In the interlaboratory tests the discharge probe was not sufficiently well defined which lead to quite high differences in some test results. The probe is now much better defined and the results (according to tests done at VTT and SP with the new method description) should be much better reproducible than those of the interlaboratory tests.

Special attention was paid to the key factor 'chargeability' in the ESTAT-Garments interlaboratory tests. The different potential methods included the EN 1149-3, Method 1 [30], STFI Method PS07 [8], Shirley Method 202 [8], Capacitance loading method [31,32] and the Polish proposal for a chargeability test [33]. The Japanese test method JIS L 1094 "Frictionally charged electricity-amount measuring method" [34] was excluded already in an earlier stage of the project [7].

The first four mentioned test methods were included in the interlaboratory test series. However, tests using the capacitance loading method, with the full name of “Test method to determine the limitation of surface potential created by electrostatic charge retained on materials”, were limited to one of the participating laboratories (John Chubb Instrumentation) and, thus, no real information on the repeatability and reproducibility was obtained. The Polish chargeability test method was not included in the study because it came evident in discussions with Polish delegates of IEC TC101 that there would be no test equipment available for the ESTAT-Garment studies.

The conclusion of the ESTAT-Garments interlaboratory tests was that the EN 1149-3, Method 1 (tribocharging) is the most potential candidate for the chargeability test method for garment fabrics used in electronics industry. The repeatability and reproducibility of the results were not in the same level as with the point-to-point resistance test, but this was expected: the level of tribocharging depends on so many factors that it is not possible to achieve high degree of repeatability and reproducibility by any tribocharging test method. The repeatability and reproducibility of results with the EN 1149-3 Method 1, however was satisfactory and every laboratory participating in the test series could clearly distinguish low-charging ESD protective garment fabrics from moderate and from highly charging fabrics. See ref. [8] for more details. The method has the benefits that it is the external electrostatic field to the fabric that is measured, and the result is dependent both on the insulating parts and conductive parts of the material, and any voltage suppression due to the fabric, thus providing a balanced view of the relevant material characteristics. Field or surface voltage measurements taken at zero and 30 seconds take account of short and medium term charging and discharge performance. Three minor changes to the standard EN 1149-3 description, however, should be done when applied to garment fabrics for electronics industry. At first, the focus should be in the chargeability of garment materials due to triboelectric charging, i.e. the main attention should be in the maximum electrostatic field strength after triboelectric charging, E_0. Secondly, Al-charging rods should be replaced by charging rods made by static dissipative polyamide (such as D-RIM material) in order to have a rubbing material at the upper (positive) end of triboelectric series, in addition to dissipative HDPE at the lower (negative) end of triboelectric series. Thirdly, the use of non-contacting electrostatic voltmeter with a voltage follower probe, placed not too close to the fabric in order to average local fabric response, should be allowed for the measurement of test item charging as an alternative for an electrostatic field meter. This test method does not only address the issue of chargeability of the fabric, but also the electrostatic shielding and the charge dissipation of the fabric, this is to be discussed later.

The capacitance loading test method does also have potential as an international standard test method. Although it does not directly measure chargeability, it gives indirectly information on factors influencing the chargeability, charge dissipation and voltage suppression. We prefer EN 1149-3 Method 1 over the capacitance loading method, firstly, because the EN 1149-3 is an international standard test method already in use for the study of protective garment fabrics, secondly, the capacitance loading test method does not measure directly the chargeability, and, thirdly, there are at present open questions for the repeatability and reproducibility of the capacitance loading test and for proper acceptance limits for the capacitance loading test.

The second key factor to control is related to the test of the ‘rate of charge dissipation’. In the ESTAT-Garments interlaboratory tests there were four test methods including the property of interest: IEC 61340-2-1 charge decay test method based on corona charging of test item [33], EN 1149-3 Method 1 (tribocharging), EN 1149-3 Method 2 (induction charging), and the ESTAT-Garments garment charge decay test method (Modified SP 2175). The performance of the conductive elements of the fabric is emphasized in the two latter methods (see ref. [7] for the discussion). Only the second method will address the surface behaviour of a fabric, mirroring real situations when the fabric is being charged by rubbing. In the IEC 61340-2-1 method, the charging of the fabric is done by spraying charges with corona needles over the surface of the test sample, it has been applied for years with success for electronics packaging materials having electrostatically homogeneous surface. The EN 1149-3 Method 1 has been applied for protective fabrics used in flammable atmospheres. In the ESTAT-Garments project the test methods were studied for state-of-the-art ESD garment fabrics used in electronics industry. Such fabrics are from an electrostatic standpoint very different to ESD packaging material or to protective fabrics used in flammable atmospheres. Also the requirements for the performance are different. State-of-the-art fabrics used for protective clothing in electronics industry are electrostatically very heterogenous consisting of conductive and insulating elements (Fig. 1). While the charge decay of ESD packaging material or even base fabric, such as pure cotton, is characterised by a single valued time constant, the charge decay of state-of-the-art ESD fabrics used in electronics industry is characterized at dry conditions by three different time constants, each being in a different order of time magnitude [8,36].

The first and major part of the charge decay, related to the response of grounded conductive threads of the fabrics, happens very fast, typically within 10-30 ms. This process is typically too fast for both for the IEC 61340-2-1 and EN 1149-3 Method 1 equipment, which fails to detect this quick part of the decay. The second and third parts of the charge decay are related to charge behaviour of base fabrics and have, typically, time constants in the order of seconds and minutes, respectively, in dry conditions. If the first and major part of the charge decay is missed, the initial value is not correctly defined. Then the behaviour of the insulating base fabric can be overemphasised in the test, which may lead to a rejection of test item for improper reasons. This is exactly what happened in the ESTAT-Garments interlaboratory tests: from the six different kinds of state-of-the-art ESD garments, all widely in use in electronics industry, only one type passed the IEC 61340-2-1 charge decay test at every laboratory (see ref. [8] for details). Therefore the conclusion of the ESTAT-Garments tests was that the IEC 61340-2-1 charge decay test method is not suitable for the characterisation of electrostatically heterogeneous fabrics (i.e., ESD fabrics with conductive threads in a matrix of base fabric), especially at dry conditions. Some ESD garments with truly fast charge decay may fail in the test for improper reasons. The reason for the negative conclusion was that the IEC 61340-2-1 method fails to reliably distinguish good and bad materials in the case of electrostatically very heterogeneous, composite fabrics (on the contrary to typical ESD packaging material which could be reliably evaluated by the method). What happens during the first tens of ms just explains why the method may fail in a correct material evaluation in the case of composite material. The same also applies to the EN 1149-3 Method 1 (tribocharging) due to similar arguments.

If the guiding principles for ESD garments are such as given in Table 1; is there a real need for a fabric level test method focusing to charge decay below the 'safe' level? The ESTAT-Garments project answers 'no'. Therefore, we are not recommending any charge decay test method for the evaluation of ESD garment material performance. Simply, there is no real need for such a test for ESD garments used in electronics industry.

The discussion of the key parameters vs. test methods, given above, is summarised in Table 5.

Table 5 Proposed test methods for the key parameters to control with reference to ESD garments and garment fabrics.

1. **Continuity of a groundable garment**:

   Test methods:
   - IEC 61340-5-1 or ESD STM 2.1 point-to-point resistance, or alternatively
   - ESTAT-Garments method "Measurement of the charge decay time of ESD-protective garment"

2. **Induction charging of ESDS by external electrostatic fields:**
   - ♦ Chargeability
     - Test method: EN 1149-3 Method 1 (tribocharging)
   - ♦ Rate of charge dissipation
     - No need for fabric level charge decay test
   - ♦ Electrostatic shielding performance of outer garment material
     - Test method: EN 1149-3 Method 2 (induction charging)
   - ♦ Voltage suppression
     - Test method: ESTAT-Garments method "Measurement of the charge decay time of ESD-protective garments"

3. **Direct ESD**:

   Test methods:
   - IEC 61340-5-1 or ESD STM 2.1 point-to-point resistance
   - ESTAT-Garments test method "Measurement of a direct discharge from an ESD protective material, such as an ESD garment/fabric"

If a garment is to be connected to ground when used, it is important to check that its seams and to have a system test for the grounding of the garment, point 1: Table 5. Also the ability to dissipate charges applied to the fabrics surface is checked. The electrostatic shielding ability and the chargeability of the fabric important parameters they are connected to the grid / mesh size of the conducting threads, point 2: Table 5. Also in this case is the ability of dissipating charges on the surface of the fabric checked, the indication from these methods are actually better than the indications from the methods under point 1: Table5. Under point 3: Table 5 the direct discharges from / to the ESD protective fabric are investigated. If applied to fabric level, the point-to-point test gives indirect information about the intrinsic properties of ESD fabrics to dissipate direct discharges. The ESTAT-Garments method does that directly.

4.3 Recommendations for test methods and limits

When we take into account the need of the three different level of testing (evaluation, approval, periodic) and the fact that Class A and Class B garments do have diverse needs for the electrostatic testing, we are now ready to give the ESTAT-Garments recommendations for the test of ESD protective garments used in electronics industry. Our principle has been to recommend a minimum number of test methods to cover all really important aspects of ESD protection at each level of testing. The ESTAT-Garments recommendations for the evaluation testing of new product to enter the markets are given in Table 6, recommendations for the approval testing for the first article or incoming material are given in Table 7, and recommendations for the periodic testing are given in Table 8.

Evaluation test of new products to enter markets should cover all important aspects of ESD protective performance. It should be done in controlled environment, preferably at 12 % RH, 23°C for washed garments and fabrics. The tests should include methods focusing both to garment properties, including workmanship (connections between sleeve-torso-sleeve), and fabric properties of which the chargeability and electrostatic screening are the most important. EN 1149-3 methods cover the fabric property testing. Garment level study could be done either by the point-to-point resistance or by the ESTAT-Garments garment level charge decay test method. Both test methods provide specific standpoints but, because of the strong overlap of properties they focus to, we do not feel it necessary to carry out both tests. Due to the diverse needs of electronics industry, we are recommending the methods as alternatives. Finally, if the ESD risks of direct discharges due to improperly functioning or used garment (garment where all panels are not grounded) would like to be assessed, the ESTAT-Garments direct ESD test would be a method for that.

Approval test will be done for garment types which have already passed the evaluation tests when entering the markets. Therefore, approval test does not have to cover all parameters of interest influencing the ESD protective performance of garment. Instead, the approval test should focus to workmanship. For Class A garments it is particularly important to verify whether all panels of garment are sufficiently well connected to ground. This can be done by the point-to-point resistance test method or, alternatively, by the ESTAT-Garments garment level charge decay test method. Class B garments do not have to be grounded in use. Therefore the point-to-point resistance test is not relevant for them. In order to have a link between the evaluation and approval tests, we are proposing to the electrostatic shielding test of EN 1149-3 (Method 2) for Class B garments at approval testing. It is focusing to an important parameter to control, and it is easy to perform. The electrostatic shielding test of EN 1149-3 is useful also for Class A garments in the approval testing. There is no special need to carry out the approval test at controlled dry humidity conditions. The test can be done in the true climate of EPA in question, taking into account the lowest possible humidity in the EPA.

Table 6 ESTAT-Garments recommendations for the evaluation test of new products to enter markets.

Evaluation tests - *Valid for both Class A and Class B garments:*

Required tests

- IEC 61340-5-1 / ESD STM 2.1 point-to-point resistance test method or alternatively, ESTAT-Garments test method "Measurement of the charge decay time of ESD-protective garment"
- EN 1149-3 Method 1 (tribocharging) for fabric level chargeability test
- EN 1149-3 Method 2 (induction charging) for the electrostatic shielding test

Optional test

- ESTAT-Garments test method "Measurement of a direct discharge from an ESD protective material, such as an ESD garment/fabric"

Table 7 ESTAT-Garments recommendations for the approval test for the first article or incoming material.

Approval test

Required test for Class A garments

- IEC 61340-5-1 / ESD STM 2.1 point-to-point resistance test method or alternatively, ESTAT-Garments test method "Measurement of the charge decay time of ESD-protective garment"

Required test for Class B garments

- EN 1149-3 Method 2 (induction charging)

Optional test for Class A garments

- EN 1149-3 Method 2 (induction charging)

Table 8 ESTAT-Garments recommendations for periodic test

Periodic test

Required only for Class A garments

- IEC 61340-5-1 / ESD STM 2.1 point-to-point resistance test method or alternatively, ESTAT-Garments test method "Measurement of the charge decay time of ESD-protective garment"

Periodic test is to verify that the ESD garment still has a desired ESD protection level after and during use. Periodic testing would be necessary only for Class A garments, because they are sensitive both to washing and to wear and tear. Washing has a tendency to rip seams. Also wear and tear, giving rise to broken conductive fibres, predominantly affects to the grounding performance of the garment, which is important only for Class A garments. The ESD protective performance of core conductive Class B garments should only improve in use because broken fibres increase garment's ability for the self-dissipation of charge through the corona mechanism [24]. The point-to-point resistance test or, alternatively, the ESTAT-Garments garment level charge decay test are the recommended methods for periodic testing of Class A garments. While the point-to-point test may be more suitable for laundries, the charge decay test does have a potential for a quick garment test when entering EPA if suitable equipment (simple automatic testers) will become available.

Required limits for the acceptance of Class A and Class B garments are given in Table 9. The upper resistance limit of the point-to-point test method is set to 1×10^{10} Ω in order allow sufficiently fast migration of charge to ground to protect ESDS having HBM withstand of 100 V. The 20 s limit of the garment level charge decay test corresponds to the 1×10^{10} Ω resistance-to-ground of garment. Although a lower limit of point-to-point resistance is not given, we would like to mention that setting the lower limit to 1×10^{5} Ω would give further redundancy for the protection against direct ESD risks. In the case where the grounding of a garment panel fails for one reason or another and the garment becomes charged, discharge current could be dissipated already within the garment to a safe level if the surface resistance of the garment is in the range for static dissipative materials (i.e. the lower limit $\geq 1 \times 10^{5}$ Ω).

Table 9 Required limits of acceptance for Class A and Class B garments

Required limits

Class A garments

♦ Point-to-point resistance	$R_p < 1 \times 10^{10}$ Ω
♦ Charge decay time of full garment	$t_g < 20$ s
♦ Chargeability	$V_0 < 500$ V (or $E_0 < 10$ kV/m)

Class B garments

♦ Chargeability	$V_0 < 2000$ V (or $E_0 < 40$ kV/m)

The limits for the chargeability test method come from the general EPA requirements. The 500 V surface potential limit is based on the supposition that in typical handling of ESDS the minimum distance between an ESDS and garment is about 5 cm, supposing that the sleeves of the garment fit well. Thus the 10 kV/m electrostatic field limit would be satisfied. For Class B garments a higher surface potential could be allowed because the principal electrostatic function of Class B garments is not in the safe handling of ESDS but in the contamination prevention. Therefore, the 2000 V EPA potential limit gives a relevant limit of chargeability for Class B garments. The field and potential limits of EPA are based on studies done at component level. They include significant safety margin when handling unassembled devices [37]. When assembled on a board, the safety margin could be highly reduced but the EPA requirements still give safe limits [19].

For the electrostatic shielding (EN 1149-3 Method 2) we do not feel it necessary to give required limits. We just note that the higher the shielding factor, the better (maximum = 1). The same applies for the direct ESD test method and for the voltage suppression part of the ESTAT-Garments garment level charge decay decay test method. Current thresholds for failure of HBM 100 V devices should be $I_p \approx 200$ mA for typical discharges from fabrics of about 10 ns duration [10,18,21], but due to the high level of test potential in the method (2000 V) we feel it appropriate to suggest slightly higher recommendation (not requirement) for the limit: $I_p \leq 300$ mA (when measured using the SP type of discharge probe). The lower the peak ESD current is, the better. Voltage suppression is the better, the lower the voltage suppression factor is (a theoretical maximum is 1.0 but, in practice, voltage suppression is defined only when it is below 0.9).

The ESTAT-Garments recommendations for test methods and limits given above are for the handling of devices susceptible to damage by electrostatic discharges greater than or equal to 100 V HBM. The recommended test methods are equally valid also if the susceptibility of ESDS is less than 100 V HBM. Depending on the susceptibility of the devices, tightened limits would be necessary to achieve desired level of ESD protection. Only Class A garments are recommended for the handling of ultrasensitive devises of ESD withstand below 100 V. Furthermore, the use of highly charging normal clothing under the ESD protective garment is not recommended (short sleeve T-shirts would be the best). Finally, sleeves of the ESD garment should fit snugly (i.e. loose sleeves should be avoided when handling truly ESD sensitive devices).

In many cases a tight short sleeved cotton T-shirt worn directly on the skin of grounded operator would be a good alternative for an ESD protective garment worn on operator's ordinary clothing. From the ESD protection point of view, such a T-shirt - operator combination may well correspond to a high quality ESD garment. None of the test methods discussed above, however, would apply particularly well for the evaluation of the ESD protective performance of such a T-shirt - operator system.

5 Application of the ESTAT Garments project results in the electronics industry and IEC TC101 standardisation projects

This section represents the personal views of Dr Jeremy Smallwood concerning the application of the ESTAT Garments results in the electronics industry and current standardisation work within IEC TC101. These views do not represent the views of TC101 or any consensus within TC101 expert groups. The author has deliberately taken a *critical approach* to reviewing the project results with standardisation and industry application in mind – any disagreement or questioning of earlier sections is no reflection on the considerable merit of the results but intended to focus and promote discussion on some areas in a difficult topic in the context of standardisation and user application within the electronics industry.

The ESTAT Garment results are very relevant to several TC101 development projects, in particular the current review of the 61340-5-1 standard, 61340-5-2 User Guide and new project work on test methods for garments used in electronics manufacture. There is also likely to be future relevance for test of garments, e.g. for use in electrostatic ignition hazards avoidance. The findings on ESD current and charge transfer measurements underline the likely usefulness of these techniques in the future, and the need for further development of the ESD probe design and measurement techniques before they can be reliably used in standard test methods.

It is an important guiding conclusion that the protective function of ESD Garments is to reduce direct ESD and external electrostatic fields to insignificant levels. External fields may be reduced by shielding fields from lower layers of clothing, by or keeping fields due to the ESD garment itself to low levels. The importance of external fields seems to be in reducing induced voltages on susceptible devices or boards and risk of field-induced CDM or CBM ESD. At least we can now say that

> **A good ESD Garment is one that cannot be the source of damaging direct ESD or allow significant external electrostatic fields in the context of its application.**

Low external fields may be achieved by reducing charge accumulation on the material (reduced charge generation or adequately fast charge dissipation) or by suppressing the effect (voltage suppression properties due to the fabric or the person's body).

Direct ESD current and charge transfer levels are a function of the resistivity and charge storage properties of the most conductive parts of the material accessible to the outside world.

The question of what levels are significant or damaging in the context of the application are more difficult to answer. The project has made valuable progress in understanding this developing assessment methods. The damaging effect of direct ESD has been related, for energy susceptible parts, to peak ESD current related to HBM withstand data. Charge thresholds for damage have also been proposed for some voltage susceptible device and CDM situations [19].

5.1 Control of ESD peak current and charge transfer

The 61340-5-1 standard is concerned with protection of electronic devices with ESD withstand down to 100V HBM. The direct ESD current damage threshold for this withstand level can be calculated from the HBM data. A worn garment must not be capable of sourcing ESD of this level and a safety factor should be built in.

This leads to the following requirement

- If the garment fabric is capable of sourcing ESD greater than the peak current and charge transfer damage thresholds it must be grounded to prevent the conductive parts from charging significantly

If the garment fabric is inherently not capable of sourcing greater than these thresholds it need not be grounded from this view, although grounding may be required for control of external fields.

The peak ESD current allowable can be linked in theory to an electrical resistance of the conductive fabric thread via a specified maximum surface voltage. The ESTAT Garments suggestion of minimum R_p 10^5 Ω should be more than adequate to give this protection. At least in theory, a specification of minimum R_p is all that is required to ensure adequate control of peak current. (This assumes that the ESD originates from the garment conductors, which may not be valid for high resistivity materials.) It has not been clearly stated whether the ESTAT results confirm this

The second consideration is charge transfer in a discharge – this could theoretically charge up a voltage sensitive device to the point of breakdown. We have as yet no suggested thresholds for this but a simple calculation based on breakdown of a FET gate can give us a guide. The role of a real ESD test such as ”Measurement of a direct discharge from and ESD protective material” would probably be limited to measuring ESD for research and materials qualification purposes, and it seems at present not sufficiently reliable for standardisation. This would not prevent TC101 developing it as a Technical Specification if it was felt to be useful.

5.2 Control of external fields

According to the ESTAT Garments recommendations, the garment must not be capable of allowing electrostatic fields > 10 kV/m at the position of the ESDS component, or surface voltages > 2 kV within 30 cm of the ESDS (Table 1). Perhaps the area of greatest concern in most cases is the garment sleeves which may come in close proximity to the ESDS part. In this context allowing 2 kV surface voltage on the garments may not be wise and the field criterion translates into 500V at 50 mm distance and reduces with proximity to the ESDS. The real ESD risk associated with such fields is poorly understood.

If a garment has external conductive fibres these can be grounded to control surface voltages and external fields. If it does not, then grounding cannot be achieved. A debate about whether grounding is ***required*** in order to achieve control of voltages and fields applies both types. If it is not required, under what conditions can the garment be assured to remain within voltage and field limits, and how can we test this?

The current IEC committee documents (101/192/CD) show that the TC101 WG5 is considering classification of garments having $R_p < 10^9$ Ω as “static dissipative groundable”.

The ESTAT findings would seem to support this thinking with “Class A” garments, but indicate that review of the permissible limits is advisable.

Many of the test methods discussed (resistance methods, SP2175) actually test the characteristics of conductive parts of the fabric. Others (61340-2-1 charge decay) emphasise the characteristics of the insulating parts of the fabric in some way. We have to be careful how we apply these methods – it is the ***field strength external to the garment*** which is found to be important. (It is arguable that it is induced charge in a typical victim device that is most important and that might be measured in some way). Does it matter if the conductive parts show fast charge decay if the external field due to insulating parts remains high? Conversely, does it matter if the external field shows long decay time due to insulating parts of the garment, if the external field strength is insignificant? Only two methods seem to address this external field evaluation directly. One is the Chubb “capacitance loading” test, which was unfortunately only able to be evaluated by the originator. The second is the EN1149-3 Method 1, discussed in more detail below. Both are fabric, rather than garment, tests and therefore are useful for evaluating materials but not for on-going performance monitoring in workplace situations.

A method of determining induced ESD threat with material surface voltages and external fields does not yet appear sufficiently developed to allow determination of thresholds for ESD damage by this mechanism. This remains a significant barrier to understanding the real requirements of an acceptable ESD Garment – we remain reliant on existing guidance from the standards (10kV/m fields, or 2kV surface voltage to be brought no closer than 30 cm, or in the context of EN1149-3 method 1 results, 500V at 50 mm distance from the fabric). In practice we have little evidence whether these levels are correct, too high or too low. There is also little documentation of any real ESD damage to ESDS in real assembly processes. It is not clear what types of ESDS and susceptibility levels might be at risk, and under what circumstances. It is therefore even debatable whether ordinary clothing poses significant ESD risks in many assembly processes, and under what circumstances they might do so. ESTAT Garments has differentiated between Class A and Class B garments on the basis of grounding and field measurement limits – but are we really justified in stating that the Class B will give significant additional ESD risk compared to Class A? Just because higher field levels are measured it does not mean that more ESD damage will occur, if both levels are below any real threshold for damage.

One significant success of ESTAT Garments in this area is in demonstrating that we can make reliable comparative measurements on fabrics using the modified EN1149-3 Method 1 test. In this author’s view it remains debateable where any limits showing “good” or “bad” garment materials should be.

The realisation that external field is a key parameter leads to the question whether simple measurement of surface fields on garments in the workplace is a direct, simple and useful method of validating garment performance in the workplace.

5.3 Grounding of garments

The conclusion that some garment materials must be grounded if they can potentially source damaging ESD, indicates that a system test for the worn garment is required in these cases. In practice grounding of garment conductive threads may be required even at higher resistances for surface potential and external field control reasons. Maximum resistance-to-ground (R_g)

requirements are necessary in these cases to indicate reliable grounding, and a minimum may be required for safety reasons.

The ESTAT Garments project classifies garments that cannot be grounded as “Class B” and “for cases where…ESD protection is of secondary importance”. Is this justified, or could it be that some materials that are not groundable could adequately fulfil the fields and direct ESD performance limits?

5.4 61340-5-1 Protection of electronic devices from electrostatic phenomena – General requirements

Initially the need for a garments user point-to-point resistance test seems to be confirmed. The existing 61340-5-1 limits may need adjustment in the light of ESTAT Garments results. If grounding a garment is required then a system test for this is necessary, with appropriate limits.

5.5 61340-5-2 Protection of electronic devices from electrostatic phenomena – User Guide

The ESTAT Garments project reports has some very useful information that can be incorporated in the guidance on garments in the 61340-5-2 document. However this will need to be selected and summarised in a suitable concise easily understood form.

5.6 Comments on main test methods for garments likely to be subjects for standardisation

Short term needs

There is an over-riding current need to produce ESD Garment test methods suitable for inclusion in 61340-5-1/2 in the short term. There is also a need to develop better test methods for use in the future. In particular, the point-to-point resistance test method will find immediate acceptance in standardisation. This is a traditional test method and inclusion of this test is already planned in the 61340-4-2 new project.

There may be an associated resistance threshold above which grounding of the garment is theoretically not required from the direct ESD view. However grounding of the garment may still be required for control of surface voltages and external fields. One aspect not made clear in this report is how much the lack of grounding can be expected to affect the external fields to a garment. If grounding of the garment is required either to control charge build-up and electrostatic fields or direct ESD, then it seems logical this must be confirmed with a system test. A simple resistance-to-ground test would probably suffice for user confirmation in the workplace. The modified SP2175 test has a strong dependence on correct grounding and might fulfil this function.

The ESTAT project has evaluated a resistance-to-ground test [8], but did not recommend it. This author would recommend reviewing these results, as well as the modified SP2175 test, to find which would provide the most simple and effective user system test for worn garments.

61340-2-1 Charge decay test

Previously a charge decay test similar to 61340-2-1 was mandatory under 61340-5-1 where $R_p > 10^{10}\ \Omega$. The current 101/192/CD did not include this requirement, and the ESTAT results as well as current field experience confirm that this charge decay test is unreliable as currently specified in this application.

Modified SP2175 "charge decay" system test

The modified SP2175 test (Annex 1) appears to be essentially a system test in which the result is affected by charge storage (voltage suppression and decay time) and charge dissipation rates (decay time) including the ground path. There may well be some merit in standardising this test – however further critical examination may be required. For example, the performance of the garment sleeve areas may be particularly important. The method of connecting to these areas for test may need further thought, especially if as recommended they are close-fitting. The practicality, and necessity, of having the subject wear specified clothing that has been conditioned for 72 hours, will need further examination. The test only evaluates the performance of the conductive parts of the fabric connected to the test electrodes.

The primary factor affecting the "charge decay time" is likely to be the condition of the conductive parts of the garment and ground path. It seems to this author that the test is primarily a system test of these parts and it is not clear whether the test would give real benefit, commensurate with the added complexity, over a simple resistance-to-ground test [8].

Chargeability of fabrics

The modified EN1149-3 Method 1 test appears to be very attractive and suitable for standardisation, especially as it is already used in Europe. Care may need to be taken in how this is implemented in order to avoid conflict at the European standardisation level.

The test seems to have several attractive properties

- It measures the external field to the surface, which is the key property of interest (although it could be argued that measurement of induced charge in a test piece near the surface would be even better)
- The test takes a balanced view of the combined effect of triboelectrification, voltage suppression in the fabric, with conducted and any other charge dissipation mechanisms
- The test assesses the field at 0 and 30 seconds, giving a realistic time dependent view of performance

Of the tests proposed and evaluated by the ESTAT project, this seems to be potentially the most useful for garment material evaluation but it is not suitable for on-going monitoring of garments in the workplace. This author would recommend giving this test a high priority for standardisation.

Fabric Shielding properties

The shielding property measured by the modified EN1149-3 Method 2 test is likely to be of interest in qualifying materials for garment usage. However it is likely to be a medium term consideration rather than having immediate need.

The need for a balanced garment level user test

It appears to this author that there remains to be identified a test that gives a balanced view of garment performance, suitable for non-destructive user evaluation of garments placed on the market. The EN1149-3 Method 1 seems to offer this balanced view at fabric level. It is to be hoped that the knowledge gained in this project will enable such a test to be developed in the future. The currently proposed user tests remain focussed on the performance of the conductive parts of a garment rather than the fundamental performance issues. This may prevent fair evaluation of garments where the conductive parts are buried, or which use innovative technologies not yet identified.

6 Conclusions

The ESTAT Garments project has brought a wealth of new information and data to the experts involved in standardisation of garments test methods. This short report has summarised only a fraction of this. An evaluation of traditional and newer test methods has led to recommendations for test methods and requirements that will be considered by TC101 experts for application in several current electronics industry standards.

The usefulness of the conventional point-to-point resistance measurement method has been confirmed. A system level test is also recommended (ESTAT-Garments test method: Measurement of the charge decay time of ESD protective garments). The EN 1149-3 Method 1 test shows great promise as a fabric level test for the measurement of chargeability of garment material. Other recommended tests methods are the EN 1149-3 Method 2, for the evaluation of garment material's electrostatic shielding performance, and the ESTAT-Garments test method: Measurement of a direct discharge from an ESD protective material, such as an ESD garment / fabric.

Comprehensive tests at controlled environment are recommended only for the evaluation of new products to enter markets. Approval tests for the first article or incoming material do not have to cover all the aspects of ESD protection which were focused in the evaluation tests. Point-to-point resistance measurement and/or the ESTAT-Garments system level test would be sufficient for periodic testing of ESD protective garments.

The ESTAT-Garments recommendations for the acceptance limits of garments largely follow the general requirements for EPA in system level ESD control standards.

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List of Annexes

Annex 1	ESTAT-Garments test method for the measurement of the charge decay time of ESD protective garments
Annex 2	ESTAT-Garments test method for the measurement of a direct discharge from an ESD protective material, such as an ESD garment / fabric

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An ESTAT-Garments test method.

Measurement of the charge decay time of ESD-protective garments.

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April 2005

CONTENTS

ELECTROSTATICS –

Protective garments: Measurement of the charge decay time of ESD-protective garments.

1 Scope

This document specifies a method for determination of the charge decay time for full garments and similar clothing intended as protection for ESD-sensitive components in electronics manufacturing.

The method is intended to verify that each panel of the garment has a connection to the ground and the overall continuity of the protective garment.

The measurement is performed with the garment worn by a person, which assures that also other phenomena, such as: charge spread out on the complete garment, voltage suppression appearing in real world situations are simulated.

The charge can in practical use appear as a result of rubbing (tribocharging) or can be induced when the clothing has been close to a charged object.

In the appendix a version of this method is presented for measuring the voltage suppression of a worn garment. This additional method can be used to test a garment if the test object isn't intended to be grounded when used and has failed the main test. The voltage suppression test could be done simultaneously with the charge decay time test. Therefore, in the method description given in the appendix only those elemements, which are different to the charge decay time test, are given.

2 Field of Application

The test method is for ESD protective garments and similar clothing intended for use in electronics industry.

3 References

[1]	SP-Report 1995:62	Methods for Measurements of ESD-Protection Characteristics of Ionisers and Garments.
[2]	SP-Method 2472	Conditions for ”ESD-approval” of ESD-protective products and -materials.
[3]	EOS/ESD-S3.1-1991	Standard for Protection of Electrostatic Susceptible Item-Ionisation.
[4]	SP-Method 2175, rev 4	Measurement of charge decay time of ESD-protective clothing.

4 Definitions

ESD: Electrostatic discharge.
EPA: Electrostatic discharge protected area in which ESD sensitive devices can be handled with accepted risk of damage as a result of electrostatic discharge or fields.
ESD protective garment: Garment (coat, jacket, smock, hood, trousers, overall or cap) that, when correctly used, should minimise risk of damage for ESD sensitive components due to static electricity.
HBM: Human Body Model, an electrostatic discharge model circuit characterizing the electrostatic discharge from a human being.

5 Sampling

At least three test samples of each specimen are required.

Make sure that the test samples are washed and dried according to manufacturers instructions. The washing and drying procedures are documented and included in the test report.

6 Test method

6.1 Principle

The ability of the garment to drain and to suppress an applied charge is measured. The measurement is performed with the garment worn by a test person. The charge is applied to the test-object by a transfer of a charge from a capacitor to any fabric panel of the test garment. If the garment is conductive or dissipative (which it shall be) the charge will spread out over the complete garment and the voltage will be suppressed by the capacitance of the garment to the test person. As the operator during the test as well as in a work situation is grounded through a wrist strap the capacitance between the garment and the operator will suppress the applied voltage. When there is a galvanic connection between the operator and the garment, the charge will be drained away. This galvanic connection can be enforced by for instance skin to garment contact, but also be more or less accidental by a local break through due to for instance high humidity or by wearing thin or non-insulating under laying garments.

6.2 Equipment

Apparatus:

1. Charged Plate Monitor. According to ref [3], p 6 and Annex B.
2. Electrostatic Voltmeter, e g Monroe 244.
3. High voltage generator, e g Oltronix A2K5-20HR.
4. Counter, e g HP 53131A/132A.
5. Capacitor 1000 pF +/- 1 %, >600 V_{DC}, tgd <0.05 %, dielectric: polypropylene or polystyrene.
6. Wrist strap, resistance 9×10^5 to 3.5×10^7 Ω.
7. Compressed air ioniser.
8. Contact clamp according to figure 1.

The test person shall underneath the test item wear coarse sweater and jeans, which shall have been conditioned in measurement environment for at least 72 h before test commences.

6.3 Testing environment

Temperature: 23 °C +/- 2 °C.
Humidity: 12 %RH +/- 3 %RH.

6.4 Pre-conditioning of test samples

The test samples shall have been conditioned in the measurement environment during at least 72 h before the test.

The test person puts on the specified clothing and the test item. The person shall wear a grounded wrist strap and stand on an insulating plate (> 10^{12} Ω), 4 to 8 mm thick, which is placed on a dissipative, grounded floor.

6.5 Test procedure and data processing

The test clamp is connected to one panel of the test item. If the test item has conductive threads or fibres, the clamp is placed so that it covers at least two rows of threads.

The test item and all exposed parts of the test person's regular clothing are neutralized with the ioniser. The operator should be grounded during this process.

The capacitor "C" and the metallic plate are charged to 520 to 550 V. S_1 is turned on and when the static voltmeter measures a voltage of 520 to 550 V S_1 is opened again. Then the charge of the capacitor is applied to the test item by turning on S_2.

The measurement is repeated so that at least 3 measurements are performed on the same test item. The test points are chosen so that all panels (over seams) of the test item are tested.

If the test item is a garment, coat or smock then the test person shall stand with horizontal underarms and with the cuffs of the sleeves extending 5 to 8 cm outside the cuffs of the clothing worn underneath, to assure a good galvanic connection between the garment and the operator's body (assuming that skin contact is the correct grounding principle for the test item). If there is another prescribed grounding principle then that should be used during this part of the test.

The charge decay time from 500 V to 100 V is measured with the counter.

6.6 Applicability

This test method can be applied to ESD protective materials with a surface resistance down to 1 kΩ, especially ESD protective fabrics. If the surface resistance is lower than 1 kΩ there is a risk of damaging the oscilloscope. This can be avoided by lowering the charging potential; as a consequence, one might also need to change the acceptance levels.

6.7 Uncertainty

The uncertainty of the voltage measurement instrument is less than +/- 3 %.

The measurement of time interval has an uncertainty of less than +/- 100 ms for measured intervals shorter than 20 s. Together with the uncertainty of the voltage measurement the uncertainty of the time interval measurement is better than +/- 0.5 % at 20 s.

The capacitance of the discharge circuit (capacitor C, cabling, switch, charged plate) has an uncertainty of better than +/- 3 %.

The capacitance of the test person to ground is 100 to 300 pF that is paralleled with the resistance of the wrist strap. This gives a discharge time (from U to 0.1 x U) of < 25 ms, which is negligible at a measured time of 20 s.

The characteristics of the clothing, worn underneath by the test person influences the test result, but cannot be theoretically evaluated.

Tests have shown the repeatability to be better than +/- 10 % for values between 1 and 20 s.

6.8 Test report

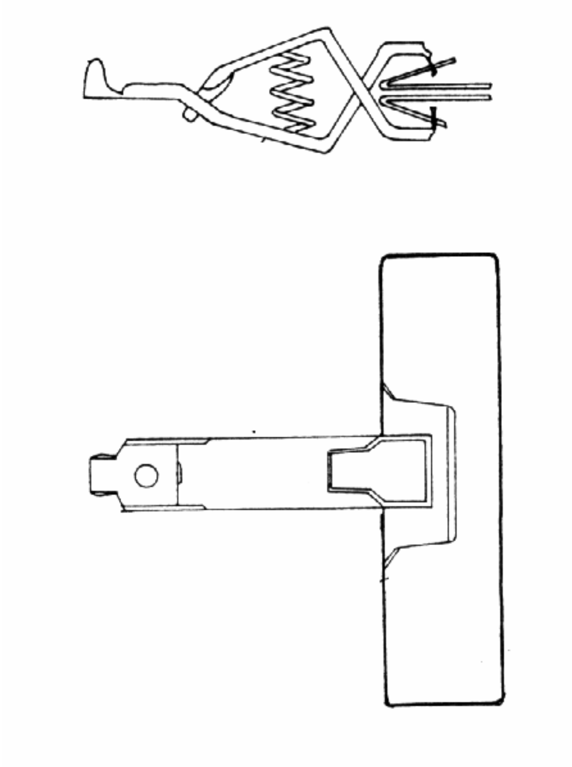
Each measured charge decay time with reference to the defined test point is reported.
Min and max measured charge decay time values are stated in the report.

The min and max values for the voltage suppression are stated in the report if applicable.

6.9 Acceptance or rejection of the results

Maximum decay time is less than 20 s.

This requirement correspond to 100 V HBM, this is the safety level that is used on most EPAs. If the safety level used on the EPA is lower than 100V HBM then the acceptance criteria must be reevaluated.



Two flat plates:
Dimensions: 25 x 100 mm.
Material: stainless steel, each plate laminated with 1 mm thick conductive rubber with a hardness of Shore A: 50 to 70.

The plates shall be affixed to the clamp to provide pivotal feature and parallel plates.

Figure 1 Example of the test clamp.

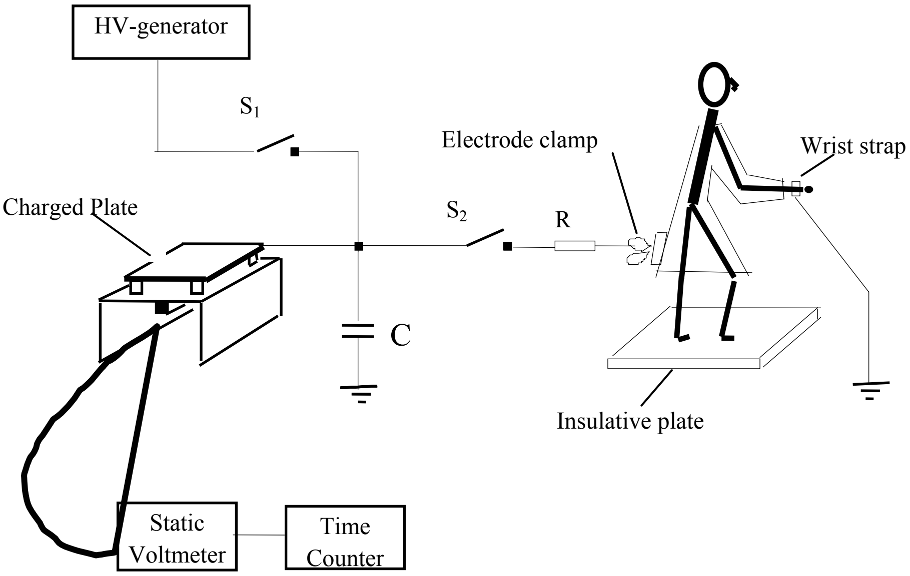


Figure 2. Test set-up for the charge decay time test.

Appendix:

ELECTROSTATICS –

Protective garments: Voltage suppression of an unearthed ESD-protective garment.

Note! Only test method description elements different to those of the charge decay time test are given below. The missing elements are like in the charge decay time part of the test method.

1 Scope

This document specifies a method for determination of the voltage suppression for full garments and similar clothing intended as protection for ESD-sensitive components in electronics manufacturing.

The measurement is performed with the garment worn by a person, which assures that also other phenomena, such as: charge spread out on the complete garment, voltage suppression appearing in real world situations are simulated.

The charge can in practical use appear as a result of rubbing (tribocharging) or can be induced when the clothing has been close to a charged object.

4 Definitions

Definitions are as in the main method description.

The following definitions are addisional:

T_o - The time at which the decay starts.
U_o - The average voltage of the time interval T: [t_o-30, t_o+10] ms, an estimate of maximum voltage
V_o - The average voltage of the time interval T: [–200ms, Time(U_o 90%)], the definition of the maximum voltage
V_1 - The average voltage of the time interval T: [Time (U_o 90%), +200ms] the definition of the end voltage.

If the time T[U_o 90%] > 200ms then we say that there is no voltage suppression. If the potential never comes below 90 % of the initial value, we also say that there is no voltage suppression.

6 Test method

6.1 Principle

The ability of the garment to redistribute an applied charge and to suppress the resulting voltage is measured. The measurement is performed with the garment worn by a test person. The charge is applied to the test-object by a transfer of a charge from a capacitor to any fabric panel of the test garment. If the garment is conductive or dissipative the charge will spread out over the complete garment and the voltage will be suppressed by the capacitance of the garment to the test person. As the operator during the test as well as in a work situation is grounded through a wrist strap the capacitance between the garment and the operator will suppress the applied voltage. When there is a galvanic connection between the operator and the garment and the garment is continues, the charge will be drained away. This galvanic connection can be enforced by for instance skin to garment contact, but also be more or less accidental by a local break through due to for instance high humidity or by wearing thin or non-insulating under laying garments.

6.2 Equipment

Apparatus:

1. Charged Plate Monitor. According to ref [3], p 6 and Annex B.
2. Electrostatic Voltmeter, e g Monroe 244.
3. High voltage generator, e g Oltronix A2K5-20HR.
4. Capacitor 1000 pF +/- 1 %, >600 V_{DC}, tgd <0.05 %, dielectric: polypropylene or polystyrene.
5. Wrist strap, resistance 9×10^5 to 3.5×10^7 Ω.
6. Contact clamp according to figure 1.
7. Compressed air ioniser.
8. At least, 500MHz oscilloscope with 1 Gs/s.

The test set up is shown in figure 2. The oscilloscope is connected to the output of the electrostatic voltmeter (not included in figure 2).

The test person shall underneath the test item wear coarse sweater and jeans, which shall have been conditioned in measurement environment for at least 72 h before test commences

6.5 Test procedure and data processing

The test clamp is connected to one panel of the test item. If the test item has conductive threads or fibres, the clamp is placed so that it covers at least two rows of threads.

The test item and all exposed parts of the test person's regular clothing are neutralized by with the ioniser.

The capacitor "C" and the metallic plate are charged to 520 to 550 V. S_1 is turned on and when the static voltmeter measures a voltage of 520 to 550 V S_1 is opened again. Then the charge of the capacitor is applied to the test item by turning on S_2.

The measurement is repeated so that at least 3 measurements are performed on the same test item. The test points are chosen so that all panels (over seams) of the test item are tested.

One should make sure that the test item is not grounded or in other ways connected electrically to the operator's body during this test.

The voltage change of the charge plate monitor with the external capacitor, due to the connection test item, is recorded with the oscilloscope.

6.8 Test report

The voltages V_o and V_1 are recorded and the voltage suppression is calculated as V_1/V_o for the defined test point.

The voltage suppressions, V_1/V_o, of the defined tests point are stated in the report.

6.9 Acceptance or rejection of the results

Maximum voltage suppresion is less than 0.80.

This requirement correspond to 100 V HBM, this is the safety level that is used on most EPAs. If the safety level used on the EPA is lower than 100V HBM then the acceptance criteria must be reevaluated.

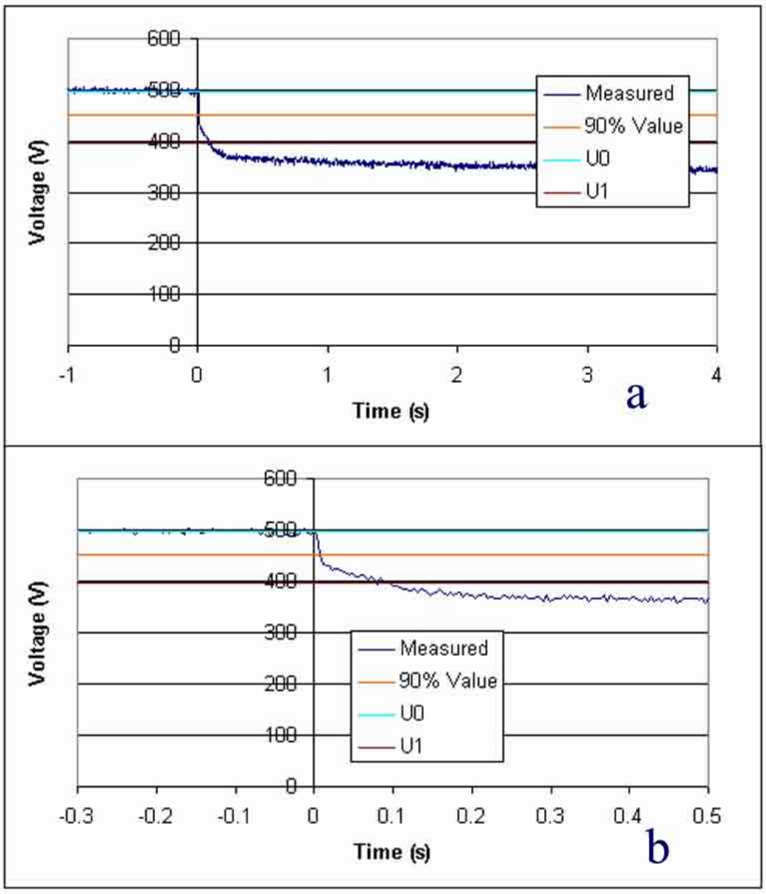


Figure 3 **(a) and (b) -** An example of recorded data used for defining the voltage suppression. The upper figure (a) has a larger time scale than the lower figure (b).

An ESTAT-Garments test method.

Measurement of a direct discharge from an ESD protective material, such as an ESD garment / fabric.

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April 2005

CONTENTS

ELECTROSTATICS –

Fabrics and inhomogeneous materials: Measurement of a direct discharge from an ESD protective material, such as an ESD garment / fabric.

1 Scope

This document specifies a method that is suitable for determining the amount of charge and the peak current from a direct discharge from an ESD-protective garment or fabric, but also small insulators or inhomogeneous materials typically found on an EPA, which typically has a surface resistance of more than 1 kΩ.

A discharge in real life can occur from a charged object to the grounded protective garment, but also it can occur to a grounded component from an incorrectly used or non-functioning garment. These situations described also apply to other ESD protective material or product as well.

The most common charging mechanism for fabrics is the tribo electric charging, but also induction and direct charging can occur. For practical reasons corona charging of the fabric is used in this method.

2 Field of Application

The method is focusing on evaluating ESD protective fabrics used in the electronics manufactoring industry. It might have to be adjusted if applied to other kind of materials used by the electronics manufacturing industry or if it is applied to ESD protective fabrics used in enviroments where flammable atmospheres can occure.

3 References

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[5] Measurement of air discharges from insulating, electrostatic dissipative and conductive materials with different ESD probes. H Salmela, J Paasi, T Kalliohaka, L Fast, Electrostatics 2005 Issue of J Electrostatics (2005).

4 Definitions

ESD: Electrostatic discharge.
EPA: Electrostatic discharge protected area in which ESD sensitive devices can be handled with accepted risk of damage as a result of electrostatic discharge or fields.
ESD protective garment: Garment (coat, jacket, smock, hood, trousers, overall or cap) that, when correctly used, should minimise risk of damage for ESD sensitive components due to static electricity.
Corona: Generation of ions of either polarity (+/-) by a high electric field.
Corona charging: A low intensity non-contact method of charging an object by corona.
Discharge signature: Characteristic waveform of a discharge event.
HBM: Human Body Model, an electrostatic discharge model circuit characterizing the electrostatic discharge from a human being.

5 Sampling

At least three test samples of each specimen are required.

Make sure that the test samples are washed and dried according to manufacturers instructions. The washing and drying procedures are documented and included in the test report.

6 Test method

6.1 Principle

The ability of a fabric / test object to quickly redistribute an amount of charge during a discharge and the characteristics of this event is measured. The discharge signature of the discharge event is recorded and the peak current and peak amount of charge is noted. The measurement is done in a controlled environment and under controlled conditions.

6.2 Equipment

Apparatus:

1. ESD discharge probe. See refs [4-5]. For fabrics intended to be used in electronics industry, the SP type of discharge probe is recommended. For materials intended to be used in flammable atmospheres, the ESL or the von Pidoll types of discharge probes are recommended.
2. Metal fabric holder, with inner measures 20 cm * 20 cm and outer measures 24 cm * 24 cm, (+/- 1 cm). Conducting rubber should be used to assure contact in between the metal fabric holder and the fabric.
3. Electrostatic field meter mounted in the centre of an at least 30 cm * 30 cm grounded plate.
4. High voltage source 0 to - 30 kV.
5. Corona brush with at least 3 needles and having a diameter of 1-5 cm. The needles should be directed in the same direction.
6. At least 500MHz oscilloscope with a sampling time of at least 2 Gs/s.

In references [1-5] discharge probes are described and discussed. In references [4-5] three types of discharge probes are defined. If the type referred to as the SP probe in those references, is used, then the diameter of the tip should be 1 mm and the radius of the tip should be 0.5 mm.

We intend to use the electrostatic field meter to measure the average potential of the fabric in combination with the fabric holder. Make sure that the fabric holder is electrically insulated from ground. Put a metal film or metal plate in the fabric holder. The distance between the ground plane and the metal plane should be (7±0.5) cm. Make sure that the distance between the fabric holder and ground in general is larger than the distance to your ground plane. Apply –1900 V to –2100 V to the metal plate in the fabric holder, and note the field that this corresponds to this voltage.

After the fabric is mounted in the fabric holder, the holder itself should be placed in front of and parallel to the grounded plate of the electrostatic field meter. Place the centre of the fabric holder directly in front of electrostatic field meter; make sure that the distance from the ground plane to the fabric is the same as the calibrated distance.

Make sure that the discharge probe is correctly calibrated and that the oscilloscope is connected to the output of the discharge probe. If the probe type requires a 50 Ω input impedance on the oscilloscope then that should be used.

The combination of the discharge probe and an oscilloscope should be calibrated. The discharge probe together with the oscilloscope should have a static accuracy of +/-5%, when measured in between -10mV to -10V. This system should be calibrated against a known voltage source and voltmeter.

6.3 Testing environment

Temperature: 23 ^{o}C +/- 2 ^{o}C.
Humidity: 12 %RH +/- 3 %RH.

6.4 Pre-conditioning of test samples

The test samples shall have been conditioned in the measurement environment during at least 72 h before the test.

6.5 Test procedure and data processing

The measurement is performed with the fabric (test object) mounted in a fabric holder if possible. If the test object is a garment, then a suitable piece of fabric, without seams, has to be cut from the garment. The size of the fabric should be chosen to fit the fabric holder.

The charging of the fabric in the fabric holder is done by the corona brush. The high voltage supply is connected to the corona brush. Place the corona brush 6 to 8 cm from the fabric that is fixed in the fabric holder and direct the corona brush towards the centre of the fabric. Slowly decrease the voltage of the corona probe until the average potential of the fabric and fabric holder reaches a level in between -1900V and –2100V. (When studying materials used in flammable atmospheres, a higher charging level of test sample may be preferred.)

Switch the corona voltage off and remove the corona probe.

Set the trigger level of the oscilloscope on a small value. The discharge probe should be held perpendicular to the fabric surface. Move the discharge probe towards the centre of the fabric slowly (0.02 to 0.1 m/s) aiming at conducting threads if possible, see figure 1. Move the probe until you touch the fabric. Repeat with increasing trigger level. When the highest possible trigger level is found, repeat the experiment 10 times. The highest peak current and the highest charge amount are presented for each of the samples. A record of the shape of one discharge event is kept.

When making the measurements, minimise variations in the distance between the test person and the fabric because changes in the capacitance between the test person hand and the test fabric may have an influence to the test results.

6.6 Applicability

This test method can be applied to ESD protective materials with a surface resistance down to 1 kΩ, especially ESD protective fabrics. If the surface resistance is lower than 1 kΩ there is a risk of damaging the oscilloscope. This can be avoided by lowering the charging potential; as a consequence, one might also need to change the acceptance levels.

6.7 Uncertainty

The uncertainty of the system consisting of the discharge probe and the oscilloscope should be better than +/- 5%, after the calibration has been performed. The accuracy of the charging procedure of the fabric is estimated to +/- 10%. The accuracy of the discharging procedure with the probe is estimated to +/- 20%; this error is mainly due to the manual handling of the probe in combination with the undefined ground path.

An overall accuracy of the measurement is set to +/- 35%.

6.8 Test report

The peak current and the maximum amount of charge transferred to the ESD-probe are kept together with the discharge signature, i.e. one discharge event is recorded and kept.

Maximum peak current and maximum charge amounts are stated in the report for each of the samples. A picture of the discharge event is also presented for one of the samples. Used discharge probe should be specified in the test report.

6.9 Acceptance or rejection of the results

Recommendation is that the maximum peak current of discharge should be less than 300 mA, measured with the SP type of probe. The smaller the peak ESD current, the better it is.

The recommendation correspond to 100 V HBM, this is the safety level that is used on most EPAs. If other level of ESD safety is required, the acceptance criteria must be re-evaluated.

There are no recommendations for the maximum charge amount since it depends on the test-setup, not only on the test material itself. The maximum charge amount is a good control parameter to see that different discharges are comparable. Therefore it should be reported.

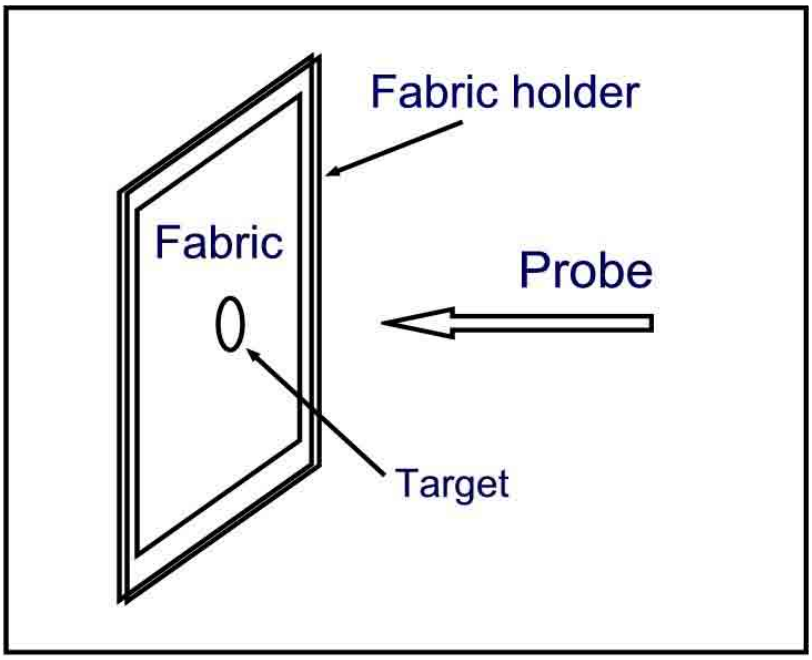

Figure 1 – Example of the test set up.