Evaluation of existing test methods for ESD garments
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Evaluation of existing test methods for ESD garments

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Author(s)

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Electrostatic discharge, ESD, protective clothing, ESD garments, measurement methods

Summary
An European research project "Protective clothing for use in the manufacturing of electrostatic sensitive devices (ESTAT-Garments)” is running with an aim to give a basis to qualify the effectiveness of clothing used for the ESD-safe handling of ESD sensitive devices (ESDS) and to develop appropriate test methods for the characterisation of such ESD protective garments.

This report is an intermediate progress report of the project focusing on the evaluation of existing test methods for ESD garments and garment fabrics. The report consists of two parts. Part A is an executive summary of the main results and conclusions. Part B is the full report giving more detailed information on how the conclusions were derived.

According to the results, current resistance based standard test methods do not satisfactorily characterise the protective performance of modern ESD garments. There are existing methods which, after modifications, have potential for test methods in future ESD garment and garment fabric standards, but completely new simple methods would be also needed. Recommendations of test methods for future ESD garment standard could be given only in spring 2005 after round robin tests are done and analysed.

Date
Tampere, 2 February, 2004

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Foreword

It is not certain that presently available standard test methods for garments used in electronics industry indicate how much the garments will protect the electronics from ESD. Therefore, the European Commission, to support the Technical Committee No 101 "Electrostatics" of the International Electrotechnical Commission (IEC), issued at late 2000 a call for a research about new test methods for ESD-garments. As a response to the call, a European research project "Protective clothing for use in the manufacturing of electrostatic sensitive devices (ESTAT-Garments)", EC contract No G6RD-CT-2001-00615, was started in early 2002. The project partners – VTT Technical Research Centre of Finland (FIN), University of Genova (I), SP Swedish National Testing and Research Institute (S), Centexbel Centre Scientifique et Technique de l’Industrie Textile Belge (B), STFI Sächsisches Textilforschungsinstitut e.V. (D), Nokia (FIN), Celestica (I) - consist of experts of electrostatics, electrostatic measurements, textile technology and electronics manufacturers (end-users of the garments). The consortium is supported by Electrostatic Solutions Ltd (UK) and Agb-konsult (S) as subcontractors.

The main goal of the three-years ESTAT-Garments project is to supply the standards body IEC TC101 with a basis to qualify the effectiveness of clothing used for the ESD-safe handling of ESD sensitive devices and to develop appropriate test methods for the characterisation of such ESD protective garments. These test methods are required as part of a suite of standards related to the provision of effective ESD damage prevention programmes according to the IEC61340-5-1 and -5-2 documents. The approach is aimed at achieving an understanding of the electrophysical processes regarding both composite textile materials and total systems, including the ESDS. The final results will be available in spring 2005.

This report is an intermediate progress report of the project focusing on the evaluation of existing test methods for ESD garments and garment fabrics. The report consists of two parts. Part A is an executive summary of the main results and conclusions. Part B is the full report giving more detailed information on how the conclusions were derived.

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PART A

1 Executive Summary

Requirements for the ESD protective clothing in electronics manufacturing industry are very diverse. Some manufacturers handling very ESD sensitive devices require high ESD protective performance for the upper 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 dust particles originating at the operator (cleanroom clothing). These have lead to situation where ESD-garments are typically 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, that is by a mixture of conductive and insulating fibres (surface conductive fibres, core conductive fibres, etc.). All the latter elements lead to very heterogeneous fabrics for 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 and use of these garments. In practice, there is a need for different types and levels of garment tests:

1. Approval test(s) for new products to enter the market, which should be done in laboratories under controlled conditions, and

2. 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.

The purpose of ESD garments is to protect sensitive electronics from ESD failures or, more realistically, to minimise risks of ESD failures to sensitive electronics. The required protection level depends on the sensitivity of the devices in production to Human Body Model (HBM) and Charged Device Model (CDM) ESD. We have identified in the ESTAT-Garments project the following parameters as the key parameters to control in order to minimise ESD failures of ESDS with reference to garments (not in any priority order):

♦ Peak ESD current
♦ Charge transfer in a direct discharge to a victim device
♦ Induced device charging due to electric field external to the garment
♦ Device charging due to accidental rubbing against the garment

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. We analysed the key parameters listed above further and obtained a list of garment and garment material (fabric) related factors influencing to the key parameters. Test methods for garments and fabrics have been evaluated with respect to that list. Peak ESD current and charge transfer in a direct ESD depend on the same fabric parameters. Device charging due to electrostatic field external to
the garment depends on the chargeability of the garment fabric, on the rate of charge dissipation of the garment/garment material (charge decay), on the electrostatic shielding property of the garment material (i.e. the property to suppress fields due to charge on underneath normal clothing by coupling the field to grounded garment elements), and on the voltage suppression due to coupling of fields to the grounded body of the operator. 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. Device charging due to accidental rubbing against the garment can be minimised only by minimising occasions for the rubbing using a proper design of ESD garments: the garments should fit snugly, particularly in the sleeves.

Because there is a need for both fabric level and garment level standard test methods (they can be in the same or in separate standards), we considered both existing fabric as well as garment test methods. 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”. The main results of the evaluation are summarised in Table A for the fabric level methods and in Table B for the full garment level methods. The tables include the list of the most potential existing test methods according to the comprehensive studies of the ESTAT-Garments project together with short comments on the suitability of the method.

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 ESD garments with core conductive garments cannot be assessed at all using resistive methods.

There are potential existing test methods for future ESD garment and fabric standards, but they all need some modifications. The modification of the methods is in progress in the ESTAT-Garments project. In addition to the methods shown in Tables A and B, there is a potential need of simple new test methods for periodic garment tests. Such methods do not have to cover all important aspects influencing the protective performance of a garment but could focus on critical parameters which could alter in use. In addition to the new garment test methods, there is potentially a need for a direct ESD test at fabric level. The development of the new methods is also in progress in the ESTAT-Garments project.

After the modification of existing test methods and the development of new methods are completed in spring 2004, round robin tests will be performed by the ESTAT-Garments project with different kinds of state-of-the-art garments and garment fabrics. Recommendations of test methods for a future ESD garment standard and a possible ESD fabric standard (if a separate document) could be given in spring 2005 after the round robin tests are completed, analysed and reported.
Table A  Summary of the evaluation of existing ESD fabric test methods

<table>
<thead>
<tr>
<th>Test method</th>
<th>Test parameter</th>
<th>Assessment</th>
</tr>
</thead>
</table>
| IEC 61340-5-1          | Surface resistance   | Suitable for homogeneous materials and heterogenous materials with homogeneous conductive/dissipative surface layer  
                        |                      | Suitable for heterogenous fabrics with surface conductive fibres only in connection with other methods  
                        |                      | Unsuitable for fabrics with core conductive fibres |
| IEC 61340-2-1          | Charge decay         | Suitable for homogeneous materials and heterogenous materials with homogeneous conductive/dissipative surface layer  
                        |                      | Potentially suitable for heterogenous fabrics with surface or core conductive fibres but not in the present form. A modification is required. |
| prEN 1149-3 Method 1 (tribocharging) | Charge decay, Chargeability | Suitable for the charge decay measurement of homogeneous materials and heterogenous materials with homogeneous conductive/dissipative surface layer  
                        |                      | Unsuitable for the charge decay measurement of heterogenous fabrics with surface or core conductive fibres  
                        |                      | Suitable for the measurement of chargeability of all fabrics by tribocharging, but the method has to be revised with respect to the choice of rubbing partner materials |
| prEN 1149-3 Method 2 (induction charging) | Charge decay, Electrostatic shielding | Potentially suitable for the charge decay measurement of all kinds of fabrics, but comparability to tribocharging is not yet shown  
                        |                      | Suitable for the measurement of electrostatic shielding property of all fabrics |
| J. Chubb’s capacitance loading method | Capacitance loading | Potentially suitable for all kinds of fabrics, but correlation to garment level still unclear, also questions about reproducibility, further studies required |
Table B  Summary of the evaluation of existing ESD garment test methods

<table>
<thead>
<tr>
<th>Test method</th>
<th>Test parameter</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 61340-5-1 ESD STM2.1</td>
<td>Point-to-point and sleeve-to-sleeve resistance</td>
<td>Suitable for homogeneous garments and heterogenous garments with homogeneous conductive/dissipative surface layer</td>
</tr>
<tr>
<td></td>
<td>Resistance to a groundable point</td>
<td>Suitable for garments with surface conductive fibres only in connection with other methods</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unsuitable for garments with core conductive fibres</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The method should be modified to also measure the resistance-to-ground for all garments</td>
</tr>
<tr>
<td>SP Method 2175</td>
<td>Garment grounding</td>
<td>Suitable for homogeneous garments and heterogenous garments with surface conductive fibres or homogeneous conductive/dissipative surface layer</td>
</tr>
<tr>
<td></td>
<td>Charge decay</td>
<td>Some modification required.</td>
</tr>
<tr>
<td></td>
<td>Voltage suppression</td>
<td>Unsuitable for garments with core conductive fibres</td>
</tr>
<tr>
<td>STFI Method PS07</td>
<td>Direct ESD</td>
<td>Potentially suitable for all types of garments, but the method has to be better specified in order to have better reproducibility of results</td>
</tr>
<tr>
<td></td>
<td>Chargeability of worn garments</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electrostatic field external to worn garment</td>
<td></td>
</tr>
<tr>
<td>Shirley Method 202</td>
<td>Chargeability</td>
<td>Unsuitable for ESD protective clothing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suitable for everyday clothing in casual environment</td>
</tr>
</tbody>
</table>
PART B

2 Introduction

Some types of everyday clothing are known to generate high electrostatic charge levels that could put ESD sensitive devices (ESDS) at risk. It has been common practice for personnel handling these devices in electronics manufacturing industry to wear a special protective clothing, called ESD garments, over their normal cloths to avoid, or at least minimise, the risks of ESD failures to ESDS due to charged clothing. 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 operators normal clothing.
- The protective garment should not itself cause similar problems. That is, it should not generate electrostatic field external to the garment and it should not be a potential source of direct electrostatic discharges.

In practice the 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 upper 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 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. All these have lead to situation where ESD-garments are typically 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, that is by a mixture of conductive and insulating fibres (surface conductive fibres, core conductive fibres, sandwich type fibres etc.), see Fig. 1 [1]. All the latter elements lead to very heterogeneous fabrics for 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 and use of these garments. In practice, there is a need for different level of garment tests:

1. Approval test(s) for new products to enter the market, which should be done in laboratories under controlled conditions, and
2. 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.

Ideally the test method(s) should be the same for both of the levels, but that is not a necessity. 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.
In the past years there have been several studies on test methods for modern ESD garments used in electronics manufacturing industry, see e.g. [2-6], as well as in flammable atmospheres, see e.g. [7-8]. These works have given valuable input material for the ESTAT-Garments project and helped us to focus our project work.

![Figure 1](image)

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

The needs for the ESD protective performance of ESD garments come from the ESD sensitivity of ESDS to be protected. Most semiconductor devices are susceptible to either of two ESD damage mechanisms: energy or voltage [9]. Devices that are susceptible to energy related damage (energy sensitive devices) may be protected by limiting the peak ESD current and energy [10]. Devices that are susceptible to internal voltage breakdown (voltage sensitive devices), and those susceptible to charged device model (CDM) damage, are protected by limiting charge transferred in direct ESD or induced on the device [10-12]. The failure mechanisms of ESDS should be taken into account when evaluating test methods for ESD garments. Any good method for ESD protective garments should assess garment’s ability to provide ESD protection.

In this report we have evaluated existing test methods for ESD protective garments and garment fabrics used in electronics industry. In Chapter 3 we give a simple electric model for
the full system under consideration consisting of operator, protective garment and sensitive device. The model would help us to understand factors influencing the ESD protective performance of a garment and, thus, to set criteria for the garment testing. In Chapter 4 we present the evaluation criteria for ESD garment and garment fabric test methods. In Chapter 5 we show the main results of the evaluation of existing test methods for ESD fabrics. The main results of full garment test method evaluation are given in Chapter 6. In Chapter 7 we discuss on the potential need for the development of new methods and modification of some existing methods. The diverse end-user requirements for the ESD garments may result in the need of garment classification with respect their ESD protective performance. That is discussed in Chapter 8. Finally, the main conclusions are shortly summarised in Chapter 9.
3 System model

The ESD protective performance of a garment cannot be studied as stand-alone. In addition to the protective garment, the ESD sensitive device as well as the person wearing the garment are required. The Operator – Protective Garment – sensitive Device (OPGD) model can be described by it’s three parts. Firstly, the operator with his different layers of normal clothing. We assume that the operator is grounded through his shoes or by a wrist strap. Secondly, the protective garment that covers at least some parts of operator’s normal clothing and, thirdly, the ESDS that we want to protect from ESD damage. In Fig. 2 we present the simple OPGD model. An electrical scheme of the system is in the lower part of the figure and an enlargement of the red box in the section above. The operator is considered to be conducting, and the insulating layer describing operator’s normal clothing is considered to have a charge density fixed on it. The sensitive device and the operator are connected to ground. Figure 2 presents the entire model of the system except for the two resistances between the ESD protective fabric and insulating layer on one hand and the resistance between the insulating layer and the body of the operator on the other. These two resistances can be omitted when there is a decent electrical connection between the body of the operator and the ESD protective garment, otherwise they are of interest.

![Simple system model covering the operator with his normal clothing, protective garment and the ESDS to be protected.](image)
A more complete electrical scheme of the garment system (without an ESDS) is given in Fig. 3, where:

- C2 is the capacitance of the wearer to ground, normally 100 pF to 200 pF.
- C1 is the effective capacitance of the charged area to the wearer. This capacitance is dependant on:
  - The effective charged area, which is determined by the type of clothing: garment, overall, etc. and also the type of fabric: pattern of conductive threads and materials, in-plane resistance of the fabric (which is dependant on humidity), etc. This area would be smaller if the different panels were not in contact with each other (e.g. due to bad seams).
  - The distance between the grounded operator and the ESD-clothing, which is determined by the size of the ESD-clothing versus the size of the operator and by the thickness of the normal clothing.
  - The material and humidity of the normal clothing.
- R1 is the in-plane resistance of the ESD-garment between the charged area of the clothing and the connection point to the operator. This resistance is the sum of the in-plane resistance of the fabric and the resistance of any seams in the current path and the contact resistance. (If the ESD-garment is not grounded, R1 is infinite. This can be the case for example due to improper design or use of the garment, a failed worn out garment, etc. In garments using core conductive fibres R1 is inherently high)
- R2 is the transversal resistance from the charged area of the ESD-garment and the body of the operator. R2 depends on:
  - The equivalent area between the operator and the charged area, which is determined by the type of clothing: garment, overall, etc. and also the type of fabric: pattern of conductive threads, in-plane resistance of the fabric (which is dependant on humidity), etc. This equivalent area would be smaller if the different panels were not in contact with each other (that is, we have bad electrical continuity in the seams).
  - The distance between the body of the operator and the ESD-garment, which is determined by the size of the ESD-garment versus the size of the operator and by the thickness of his or her normal clothing worn between the ESD-garment and the operators’ body.
  - The material and humidity of the normal clothing.
- R3 is the resistance of the operators grounding system: it can be through a wristband or conductive shoes in combination with conducting flooring. This resistance should be less than 35 MΩ in the electronics manufacturing ESD Program according to IEC 61340-5-1 [13,14].

From this scheme it is obvious that: If R1 is low and R2 is high, a good grounding of the ESD-garment is important, while; if R1 is high and R2 is low, the direct grounding of the ESD-garment is of less importance. It can also be seen that the higher C1, the lower the voltage on the ESD-garment for a given charge.

We also studied the relative effects of R1 and R2. It was found that at normal humidity of 40 % RH or more at room temperatures, the normal clothing of a typical operator under typical action is humid enough to provide an reasonable effective path for a charge to ground through R2 (transversal resistance from the ESD garment surface to the operator body through normal clothing). At dry conditions (12 % RH), however, R2 was high and R1 (in-plane resistance between the ESD garment, including seams between garment panels, and the
connection point to the operator) provides the only effective ground path for a charge to ground.

![Electrical scheme of inhabited ESD garment](image)

*Figure 3 Electrical scheme of inhabited ESD garment*
4 Evaluation criteria for fabric and full garment tests

4.1 Risk of damage to electronics with reference to charged clothing

There are two main failure mechanisms for ESD sensitive devices. Most of the devices are sensitive to the energy of the discharge. Some devices are more sensitive to internal overvoltage due to ESD. Energy sensitive devices fail by the high discharge current heating a small volume of material to a failure temperature. The failure temperature is often the melt 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 sensitive devices is the discharge power instead of discharge energy. In voltage sensitive devices, the voltage sensitive part fails when a 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 sensitive device damage.

An ESD failure caused by charged clothing can potentially happen in three different ways:
1) by a direct discharge to a device
2) by discharge from a charged device
3) by radiation, i.e. by an induced EMI (electromagnetic interference) pulse due to ESD.

We have in the ESTAT-Garments project identified and quantified the risks of ESD damage to ESDS with reference to the three mechanisms. The results will be published in detail elsewhere [15]. Here we shortly summarise the main results.

4.1.1 Risk from direct discharges

Direct discharges from the body of the operator, from unearthed or improperly earthed conductive threads of the garment, from metallic garment pieces such as press studs, or from insulating surfaces of the garment fabric are related to improperly worn, working or designed ESD garments, respectively. Direct discharges may cause damage by charge injection to the device. This could occur whether or not the device is grounded.

In general, a discharge between a garment and a device may occur when:
- A charged garment approaches a grounded or non-grounded device
- A charged device approaches a garment part, which may be grounded in the case of a conducting part

Garment characteristics should be chosen so that neither of these possibilities can give significant ESD damage risk. In the studies we have found that risks of ESD damage are minimised when the surface resistance of conductive garment elements are in the range of
electrostatic dissipative materials (from $1 \times 10^5 \Omega$ to $1 \times 10^{11} \Omega$ according to [13]) and there are no continuous insulating areas in the garment exceeding the size of about 20 mm x 20 mm. That is valid even in a case where the garment grounding is not working ideally. Metallic fibres as well as other metallic garment pieces directly at the garment surface form an increased ESD risk for all ESDS. Charged carbon fibre based threads form a clear risk only for the most sensitive devices with HBM ESD withstand voltages, $V_{HBM}$, below 100 V at realistic charging levels [15]. Examples of typical ESD waveforms from charged, unearthed fabrics commonly used in ESD protective garments are given in Fig. 4: (a) represents an ESD from stainless steel threads charged to 2 kV, and (b) an ESD from surface conducting, carbon fibre based threads charged to 2 kV [16]. Direct discharges from normal, insulating fabrics also resemble HBM characteristics. The highest peak ESD current we have measured from a normal clothing surface charged to only about 700 V was 0.8 A. That would expose energy sensitive devices with $V_{HBM} < 2$ kV to a great risk of damage.

![Figure 4](image-url)

Figure 4  ESD current waveforms from unearthed ESD fabric charged to 2 kV: (a) fabric with stainless steel threads, (b) fabric with surface conducting carbon fibre threads. Only the initial part of the discharge curve is shown in the figures.

4.1.2 Device charging and CDM damage risks

The second important ESD risk with reference to garments is associated with garment originated charging of a device. The device becomes, at first, charged and, after that, gets ground contact giving rise to electrostatic discharge (CDM type of ESD). A device may charge by two principal methods:

- Firstly, accidental rubbing of the package against the garment material may cause charging by triboelectrification.
- Secondly, a device in an electrostatic field arising from the garment will have voltage induced on it in response to the field. Component parts of the device (an input gate of IC, or a component on a printed wiring board) may also experience induced voltage stresses.

The risk threshold is reached when the charge induced or generated on the component reaches the device CDM withstand voltage level. Thus from the ESD control point of view it seems reasonable to place threshold on device charging. Also an entire Printed Wiring Board (PWB) may become charged. It has been shown that devices assembled on a PWB can be more easily damaged by ESD (Charged Board Model ESD, CBM) than at component level (Charged
Device Model ESD, CDM) [17,18]. A PWB conductor has much higher capacitance than a single device and, thus can store much more charge than a device.

To evaluate the ESD risks due to accidental rubbing of a device or a PWB with the garment fabric (e.g. by garment sleeve), we made tests with different kinds of ESD garments and PWBs. Every combination resulted in PWB charging up to several hundreds of volts. A PWB charged to 100 V can in a CBM discharge result in peak ESD current of the order 1 A and charge transferred in the discharge of the order 1 nC [18]. Therefore the risks due to device or board charging by accidental rubbing with garment fabric are of real concern (perhaps this is the most severe ESD risk with reference to ESD garments if ESD control is well done). Basically all ESDS having ESD withstand voltages below about 1 kV CDM and 2-4 kV HBM are at a risk of failure due to the accidental charging by rubbing.

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 PWB assembly – fabric combination where triboelectric charging is high for any ESD fabric. These risks of ESD failures can be minimised only by minimising occasions for the accidental rubbing using a proper design of ESD garments: the garments should fit snugly, particularly in the sleeves.

When considering device charging by induction due to charged clothing, the key parameter is the electrostatic field external to the garment in which the device is located. Electrostatic fields external to the garment may be dependent on:

- Triboelectric chargeability of the garment material
- Rate of charging of the garment materials
- Rate of charge dissipation of the garment
- Suppression of fields by coupling to the body of the person wearing the garment
- Suppression of fields by coupling to the grounded, conductive fibres of the garment material
- Ability of the garment material to shield the electrostatic field of underlying garments

Strong electrostatic field, however, is required to charge an ESDS to a level where an ESD failure is possible. At component level (CDM) the recommendation given in IEC 61340-5-2 that ESDS should not be exposed to electrostatic fields in excess of 10 kV/m [14] gives a significant safety margin for ESDS with HBM withstand voltage of >100 V. The corresponding ANSI/ESD S20.20 limit is ~7 kV/m [19]. But when the $V_{HBM}=100$ V device is assembled on a PWB, the safety margin can shrink to a negligible level [20]. Due to the high field limit, the risk is real only when the charged garment is sufficiently close to the device. For 100 V surface potential the 10 kV/m limit is exceeded at distances ≤1 cm in homogeneous field. At 20 kV surface potential (still possible for inhabited normal clothing at dry humidity) the limit is exceeded at distances ≤2 m in homogeneous field. In practice the field is not homogeneous and, therefore, the distance within which the risk is real is only a few tens of centimetres. In that close operating distance the use of ESD protective garments, in order to shield and drain to ground the field from underlying clothing, is important in reduction the ESD threats to damage of ESDS.

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1 Technically ANSI/ESD S20.20 says that all process essential insulators that have electrostatic fields that exceed 2000 V should be kept at a minimum distance of 12 inches from ESDS items.
4.1.3 Risk of induced EMI currents

Risks of ESD failures by radiation are related to EMI currents induced by nearby ESD, such as a discharge from operator’s ordinary clothing to his grounded ESD-garment. In our tests we measured EMI currents induced on test circuits with maximum peak values of about 20 mA. With reference to garments, the risk is relevant only when handling MR heads or other components with ESD withstand less than a few volts. The risks can be minimised, when necessary, by paying attention on the clothing used under the ESD garment. Furthermore, the electromagnetic shielding performance of ESD fabrics is negligible in the frequency range of interest. Therefore, the risk mechanism is not of concern when evaluating the protective performance of ESD garments, i.e. the electromagnetic shielding performance of a garment or garment fabric is not of relevance.

4.1.4 Importance of garment grounding

Most of the ESD risks associated with charged clothing are minimised by using ESD protective garments where all garment panels are grounded satisfactorily well. It would require that the conductive fibres shall be grounded and all parts of the garment shall be connected to each other (or to ground), i.e. the conductive parts of the garment should be "continuous". Depending on which ESD safety level is required, exceptions could be allowed, particularly if the system is used in higher humidity (>40 %RH) where a charge on a garment surface can drain (slowly) to ground through the normal clothing of the operator.

A part of a garment (fabric panel), which is insulated from the rest of the garment, acts in principal as a non-grounded garment and constitutes an ESD-risk. (Like all non-grounded conducting objects inside an EPA.) The level of the risk depends on the resistivity of the conductive elements of the panel (risk of direct discharges) and the strength of the electrostatic field outside to the garment panel (risk of induced voltages).

Note: A core conductive garment cannot be adequately grounded due to the buried conductive elements and can never be considered as continuous at dry conditions. We cannot, however, conclude anything from this in itself about their potential value in ESD protective garments. Measurement of peak current and charge transferred in ESD sourced from a fabric can be used in the evaluation of risk of damage from direct ESD, whether the material is groundable or not. Similarly, measurement of external electrostatic fields gives a general good method of evaluating risks from induced potentials on devices.

4.1.5 Key parameters to control

The following parameters have been identified as the key parameters to control in order to minimise ESD failures with reference to garments (not in a priority order):

♦ Peak ESD current
♦ Charge transfer in a direct discharge to a victim device
♦ Induced device charging due to electric field external to the garment.
♦ Device charging due to accidental rubbing by garment

Voltage at the device pins would be also a correct parameter to control from the device failure point of view, but it is very device specific parameter and thus not applicable as a parameter characterising the ESD protective performance of a material. Furthermore, the fourth
parameter in the list—device charging by rubbing—cannot be influenced in practice much by a proper choice of the ESD protective garment material. It is more a garment design issue. Therefore we will henceforth pay attention to the first three parameters in the list.

Peak ESD current and device charging are not standard device ESD test parameters. Current and charge thresholds for damage, however, can be easily derived from standard device test parameters [10]. HBM ESD withstand voltage test [21] is a standard measurement which is performed on the majority of devices. If the device HBM withstand voltage $V_{HBM}$ is known, the peak ESD current threshold $I_{fHBM}$ can be calculated from

$$I_{fHBM} = \frac{V_{HBM}}{R_{HBM}}, \quad (1)$$

where $R_{HBM} = 1500 \, \Omega$ [10]. Thus a threshold of 100 V HBM gives a peak current threshold of 66.7 mA. In general, the allowable current is 0.67 mA per Volt HBM withstand. The failure current threshold is valid (at least) for energy susceptible devices for exponentially decaying waveforms of durations similar to the HBM pulse $t_{HBM} = 150 \, \text{ns}$. For any essentially other pulse duration a correction factor should be used (see [10] for details).

A charge threshold for failure, $Q_f$, can be derived from standard CDM test data. If the device CDM withstand voltage $V_{CDM}$ is known, a charge threshold value $Q_f$ can be calculated from [10,12]

$$Q_f = C_d V_{CDM}, \quad (2)$$

where $C_d$ is a device capacitance. If the device capacitance in the CDM test configuration is known, this value should be used in Eq. (2). If we have to estimate $C_d$, choosing a low value for $C_d$, such as 1 pF, would give a safe estimate for use in charge threshold calculation. For example, if the CDM withstand voltage of a device is 1000 V, the charge threshold calculated using $C_d=1 \, \text{pF}$ is then 1 nC. Induced charge or triboelectrically generated charge less than this value would not be expected to cause CDM damage.

For some voltage sensitive devices, such as MOSFETs, the charge threshold for failure, $Q_f$, is defined in a different way [10]. As an example, consider the device is MOSFET that has gate capacitance $C_g$ and gate breakdown voltage $V_{gbr}$. The charge threshold for breakdown is

$$Q_f = C_g V_{gbr}, \quad (3)$$

For a MOSFET of gate capacitance 10 pF and gate breakdown voltage 20 V, the charge threshold is 0.2 nC. The device charging may happen by induction, triboelectrification or conduction.

4.2 Evaluation criteria of test methods

The purpose of ESD garments is to minimise risks of ESD failures to sensitive electronics with reference to clothing. Any good test method for garments or garment materials should assess that. The key parameters to control, defined in Chapter 4.1, are not necessarily such which could be easily, reliable and repeatable measured in garment or garment material tests. Therefore we processed the problem further and defined factors influencing to the key parameters. The factors were identified as “easily” measurable parameters. The list of the factors is given in Table 1.
Table 1 Electrostatic factors influencing to the key parameters to control with reference to charged ESD garments

| 1. 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 |

| 2. 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 happen in three 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 |
Let us take a closer look to the three mechanisms of charge dissipation \[5, 22\], see Fig. 5.

1. **Conduction**: If the fabric is grounded, the charge on or near the conducting element of the conducting thread will be conducted to earth.
   The conduction mechanism depends on
   - the resistivity of the threads
   - the resistivity of base material
   - the resistance over garment seams, in such cases when the charge cannot be effectively drained to ground through the normal clothing of the operator

2. **Induction**: The charge on the insulating base fabric induces a charge of opposite polarity in grounded conductive threads leading to partial neutralisation of the total charge. The phenomenon can also be understood as an increase in the capacitance caused by the grounded threads which lower the effective potential to be observed. Basically it is a question of voltage suppression due to field coupling to grounded fibres, but above we defined the voltage suppression as the coupling to operator’s body. Secondly, the mechanism appears like charge decay when the conductive elements have a finite resistivity.
   The induction mechanism depends on
   - aspects of conductive grid design and materials used in particular fabrics
   - the capacitance of the charged garment system

3. **Corona**: Partial neutralisation of charges on the base fabric may also occur by receiving the air ions formed in nearby corona discharges on conductive threads, if the corona onset field strength in the region is exceeded.
   The corona mechanism depends mainly on the structure of the conductive threads.

![Figure 5. Three charge dissipation mechanisms of ESD fabrics](image-url)
In the ESTAT-Garments project we have studied the charge decay on ESD fabrics by the three mechanisms in more detail. It has been found that for grounded ESD fabrics charged by controlled triboelectrification [23] there are three clearly distinguishable regions and processes in the charge decay curve at dry humidity (12 % RH). There is a fast initial charge decay response with a time constant (charge decay to $e^{-1}$ of the peak value) of only 10-30 ms, mirroring the initial response of conductive threads [24]. The second region has a time constant typically of about a few seconds at 12 % RH. The third distinguishable region has a time constant typically of tens of seconds or even minutes, mirroring the slow charge migration on the base fabric. In ungrounded fabrics the corona discharge is the principal charge dissipation mechanism. We made experiments with different kinds of charged core conductive fabrics and found that the corona mechanism effectively limits the fabric charging of core conductive fabrics typically to 2-5 kV by self-decay [25].

Risks of direct discharges from garment into devices are minimised when all the garment panels are grounded satisfactorily well. Also charge decay through conduction and induction mechanisms as well as electrostatic shielding depend on the grounding of the garment. Therefore the evaluation of the ESD protective performance of a garment should include the measurement of

- the resistance to ground or to a groundable point of the garment
- the integrity of the electrical resistance of the seams.

Note that we cannot conclude anything from the measurement of resistance-to-ground of a garment panel in itself about the potential value of the garment as an ESD protective garment. Measurements of the factors of the key parameters to control would always give the principal information on the ESD protective performance of a garment.

Accordingly, it will be important to distinguish two types of ESD garments and fabrics

- garments and fabrics that require grounding for ESD safe operation
- garments and fabrics that do not require grounding.

Most of the factors above are directly related to the structure and electrostatic properties of the garment material and, thus, can be studied by fabric tests. Only few factors require potentially full garment or system tests related to earthed or non-earthed environment (especially the operator). The list of the factors has been used for the evaluation of existing test methods for both ESD fabrics and full garments in Chapters 5 and 6.
5 Evaluation of existing test methods for fabrics

5.1 Selection of methods

The first task of the work was to make a survey of existing test methods for the characterisation of the electrostatic (ESD protective) performance of the fabrics used in ESD garments. The survey covered international and major national standards worldwide as well as a few commonly used industrial and laboratory methods. Some preliminary screening of the methods was done based mainly on the experience from the European research project SMT4-CT96-2079 “The evaluation of the electrostatic safety of personal protective clothing for use in flammable atmospheres” [7,8]. Special attention was paid to include test methods applying different kind of charging techniques and potentially monitoring factors listed in Chapter 4.2. When there was no existing IEC or ANSI/ESD standard test method for a specific factor, we made an initial preference over the methods under consideration in the EN 1149 series of standards in Europe. The selected test methods after the pre-screening for the evaluation of existing test methods at fabric level are listed in Table 2. Main results of the evaluation are presented in Chapter 5.3. A brief method description is given there for all other than existing IEC standard test methods, in which case a reader is referred to the original standard for more details.

Table 2 Existing fabric level test methods selected for the comprehensive studies of the ESTAT-Garments project

| ♦ Resistive methods of IEC 61340-5-1 (surface resistance, point-to-point resistance) |
| ♦ Resistive methods of EN 1149-1-/2 (surface resistance, vertical resistance) |
| ♦ Surface resistivity according to EN 100015-1 |
| ♦ Induction charging test according to prEN 1149-3 |
| ♦ Triboelectric charging test according to prEN 1149-3 |
| ♦ Charge decay test by contact charging (VTT-method) |
| ♦ Corona charging test according to IEC 61340-2-1 |
| ♦ “Capacitance loading” test of John Chubb (corona charging) using JCI155 and JCI176 measurement devices. |
5.2 Types of test fabrics

We used in the study totally 18 different kinds of state-of-the-art fabrics for garments used in electronics manufacturing industry. The fabrics include surface conductive fibres (Bekinox, Resistat, Beltron), hybrid conductive fibres (Megana), core conductive fibres (Negastat), and stainless steel fibres. Cross sectional optical images of example fibres are shown in Fig. 6. The grid size varied from 3 mm x 3mm and 5 mm x 5mm to 10 mm x 10 mm. The base fabric was either pure polyester (PES) or polyester-cotton mixture (PES-CO). There were also pure PES and PES-CO base fabrics in the tests.

Thus there were both electrostatic homogeneous and heterogeneous fabrics in the study. In this work we have defined the terms as follows:

**Electrostatic homogeneous material**, consisting of a uniform textile fibre material or a mixture of several different fibre materials, which do not have extremely high difference in the electric conductivity. (For example, a fabric made from cotton and polyester fibres is homogeneous, but a fabric made from cotton and steel fibres is inhomogeneous because the electric conductivity of the fibres differs to more than 20 orders of magnitude.)

**Electrostatic heterogeneous (inhomogeneous) material**, consisting of several components of material (composite material, laminates, coextruded materials, multilayer ensembles) where one component is a ‘normal’ textile material and another component is a conductive material, the difference in the electric conductivity of the components being several orders of magnitude.

Electrostatic heterogeneous fabric materials can be further divided into further categories given in Table 3. The Table does not only cover the state-of-the-art ESD fabrics of the study but includes also fabric types which may be developed in the future. The classification to different types of electrostatic inhomogeneous fabrics is important for the evaluation of different test methods, as will be seen in the next section.

Finally, the fabrics can be classified with respect to whether they are galvanic groundable or not. Cleanroom fabrics with (type B2) core conductive fibres typically cannot be effectively earthed (i.e. they have a surface resistance >1x10\(^{11}\) Ω) at dry humidity (12 % RH, 23 °C).

**Table 3 Types of heterogeneous materials**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type A</strong>:</td>
<td>packages of several homogeneous material layers in the whole area (e.g. laminates, coated, co-extruded, multilayer (conductive/dissipative layer outside or inside))</td>
</tr>
<tr>
<td><strong>Type B</strong>:</td>
<td>combination of (in general) insulating basic material with (small weight parts) of conductive components (in the kind of fibres or threads)</td>
</tr>
<tr>
<td>- Type B1:</td>
<td>surface conductive</td>
</tr>
<tr>
<td>- Type B2:</td>
<td>core conductive</td>
</tr>
<tr>
<td><strong>Stainless Steel</strong></td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>---------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td><strong>Surface Conductive</strong></td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Core Conductive</strong></td>
<td><img src="image5.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Hybrid Conductive Type 1</strong></td>
<td><img src="image7.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Hybrid Conductive Type 2</strong></td>
<td><img src="image9.png" alt="Image" /></td>
</tr>
</tbody>
</table>

Figure 6 Optical images of the side-view and cross-section of typical conductive threads used in some fabrics and garments. The objective used was a dry objective of 40× magnification. The field width of the pictures is 236 microns.
5.3 Results of the evaluation

5.3.1 Resistive methods

Resistive measurements have traditionally been the way to qualify materials where static electricity is thought likely to cause problems or present risks. Resistive methods are simple and convenient. Results of resistive measurements, however, depend on several factors, such as:

- type, geometry and distances of the measuring electrodes
- measurement voltage and measurement (electrification) time
- contribution of surface and volume resistivities
- type of material (not all materials can be realistically evaluated by the means of resistive quantities, for example some heterogeneous fabrics)
- humidity

The influence of the first three factors in the list on the results are standardised by specifying the measuring electrodes and other factors of the measurement procedure. That has resulted in standard test methods. In this work we have considered the following fabric level test methods: the surface resistance and point-to-point resistance methods of IEC 61340-5-1 [13], the surface resistivity measurement methods of EN 1149-1 [26] and EN 100015-1 [27], and the vertical resistance method of EN 1149-2 [28]. In this report we do not give the method descriptions but refer to the standard documents for details. The different surface resistance and resistivity measurements can be compared by using specific, electrode dependent, conversion factors.

The surface resistance/resistivity methods of IEC 61340-5-1, EN 1149-1 and EN 100015-1 gave typically similar results for homogeneous and type B1 (surface conductive) heterogeneous materials and the correlation of results at different test houses was high. In general, the resistive tests are easy to perform and results are typically reliable when the surface resistance, $R_s$, of the material under test is less than $1 \times 10^{10}$ Ω. When measuring materials with $R_s > 1 \times 10^{10}$ Ω, great attention should be paid to the used instrumentation, especially to the wiring, and how the influence of external disturbances are minimised. Resistance measurement results performed in the field (at a production plant etc.) are seldom reliable in this high resistance range.

The main issue, however, is how well they characterise the ESD protective performance of the material. That depends strongly on the type of the material.

For homogeneous materials the resistive test (surface resistance or point-to-point surface resistance) cover most of the key parameters to control given in Table 1. Only the chargeability is not characterised by any resistance. It has been shown both theoretically and experimentally that there exists a clear correlation between the surface resistivity and charge decay time for homogeneous materials, Fig. 7. The resistive tests should cover most of the key parameters to control also for Type A heterogeneous materials when the conductive or dissipative layer is in the surface. In some cases it can be considered as the only test required.
For heterogenous Type B fabric materials the situation is complex. The ESD protective performance of Type B2 fabrics with core conductive fibres cannot be characterised at all by any resistive method, because the measuring electrode cannot be inherently in galvanic contact with the conductive elements of the fabric. For Type B1 fabrics with surface conductive fibres the measuring electrode can be in galvanic contact with the conductive elements of the fabric, but it is very uncertain how well the measurement correlates with the ESD protective performance of the fabric. For Type B1 heterogeneous fabric the resistive methods measure an average of the surface properties covering both the conductive threads and the base fabric in undefined manner. Most of the key parameters to control in Table 1 are influenced by the resistivity of the conductive fibres of a Type B1 heterogeneous fabric – not by an average surface resistance. For Type B1 fabrics the electrical contact between the fabric and the measuring electrodes depends also on the texture and surface roughness of the fabric. It is uncertain how well an IEC 61340-5-1 surface resistance test result correlates with the correct resistance (conductive fibre resistance) to control in state-of-the-art heterogeneous garments. Other methods are required in order to characterise the ESD protective performance of the material.

The vertical resistance test of EN 1149-2 forms a special case of resistive test. The method is universal for all types of materials. Classically it has not been of concern when assessing the ESD protective performance of outer clothing, because the charge migration to ground is designed to happen on the garment surface. The vertical resistance test has an importance when evaluating the electrical safety of the ESD protective garment in those situations where the electrical safety is of concern.

5.3.2 Charge decay test methods

Electrostatic charge build-up depends on the balance between charge generation and charge dissipation. If the charge is dissipated more quickly than it is generated, no static electricity builds up. Therefore, the measurement of charge decay of material has traditionally belonged to basic electrostatic tests, in addition to the resistance measurements. The rate of charge dissipations belongs also to the key factors of Table 1. The term ‘charge decay’ covers the potential created by rubbing a material or surface, initially at earthed potential, and the time (after rubbing) taken for this voltage to fall away as the charge migrates away [30]. The measurement of the charge decay of a material, however, is not as straightforward as the
measurement of surface resistance. The reason for this is that the charge decay of electrostatic dissipative or insulating materials, at given environmental conditions, depends on
- the intrinsic material properties
- how the charge is generated on the tested material (initial charge distribution)
- the initial density of the charge generated on or in the tested material
- how the material is grounded
- the geometrical and dimensional arrangement of the system.

As a result the measured charge decay curve may depart considerably from the ideal exponential form and the measured time constant can vary with measurement conditions even for homogeneous materials [31,32]. With heterogeneous materials the situation is even more complex. There can be significant differences in the results between different charge decay test methods and even between results from different test set-ups of the same method.

The complexity of the charge decay measurement has lead to variety of different test methods. The methods can be fundamentally discriminated by the way how the charge is generated on or in the test sample:
- triboelectric charging
- induction charging
- contact charging
- corona charging.

A recent review of different known charge decay methods is given in ref. [30]. Because of the five factors influencing the charge decay listed above, there is no single universal, ideal charge decay test method for all materials. There are, however, suitable methods for limited use. When evaluating charge decay test methods for a specific use (such as for the characterisation of ESD garment fabrics), the following criteria should be kept in mind:
- the method should have demonstrated relevance to end-user applications,
- a non-tribocharging method should have demonstrated comparability to tribocharging.

In this report we consider in more detail one fabric level method from each charge generation category:
- IEC 61340-2-1 method [33] representing corona charging methods
- prEN 1149-3, method 1 [34] representing tribocharging methods
- prEN 1149-3, method 2 [34] representing induction charging methods
- Charge plate monitor method (VTT-method) [35] representing contact charging methods.

We have analysed more fabric level methods in the project but here we focus on the most potential ones. Specific method descriptions are found in the references.

5.3.2.1 Charge decay time according to IEC 61340-2-1 (corona charging method)

The principles of the method and test set-up are described in ref. [13] Annex B, method A, and in ref. [33], point 4.3. In the method evaluation studies we used three different devices at three laboratories from two different manufacturers. There was good correlation of results done at similar equipment at different laboratories, but there was high scattering of results for some samples with different test equipment. The probable reason for the scattering is different amount of charge deposited on the sample surface at the same corona voltage.

The method seems to be very suitable for electrostatic homogenous materials with sufficiently high surface resistance of about ≥10^9 Ω. For more conductive materials the charge decay time
would be too fast to be measured using this technique because of the 20 ms initial delay [13,33] between the sample charging by corona and the start of the sample potential measurement. The method is suitable also for heterogeneous Type A materials where the electrostatic dissipative layer is on the surface. Correlation of the charge decay results with tribocharging technique has been shown, see e.g. [38]. The charge is deposited on the sample surface, like in tribocharging.

With Type B heterogeneous materials (surface and core conductive materials), however, there are severe problems in the use of the method as it is described in the standards. In the present form the method cannot correctly characterise the ESD protective performance of surface and core conductive ESD materials. The problem is pronounced at low humidity but is present also at normal conditions. The principle of the method itself is fine and universally suitable to all kinds of materials. The problem is how the results are interpreted in the current standards (IEC 61340-2-1 and IEC 61340-5-1). The use of the 10% criterion [13] leads too often a rejection of good ESD material for improper reasons (measured decay time $t_{10} > 2$ s). In reality the 10% decay time could be $<< 2$ s, but the measurement gives a very different result. The problem arises from the 20 ms initial delay of the measurement. In a heterogeneous material consisting of highly conductive elements in an insulating matrix (such as ESD fabrics with surface or core conductive fibres) the majority of the charge decay happens during the first 20 ms, which are missed in the measurement. After that the charge decay behaviour emphasises the slow charge decay processes on the insulating base fabric between the conductive fibres [24]. For example, the initial surface potential of an ESD garment fabric, with surface conductive fibres (5 mm x 5 mm grid) on a PES base fabric, at $t=20$ ms after the corona charging was about 300 V. The use of the 10 % criterion [13] leads to unpractically low final potential values, in this case 30 V. Below 100 V the influence of insulating base fabric on the behaviour of the material is pronounced, easily leading to decay times of several seconds or even tens of seconds. Measured charge decay times do not characterise the material behaviour in a proper way: Good ESD protective materials can be rejected for improper reasons. One can also argue that, is there any meaning to measure the surface potential below 100 V where the ESD risks are negligible for $V_{HBM}=100$ V devices. Our results are in accordance by Holdstock’s findings [36].

In IEC 61340-5-1 there is a statement in Annex B1.5 that “If it is not possible to achieve an initial voltage at least twice the risk threshold voltage with a corona voltage of at least 7 kV, then it shall be recorded that the rate of charge dissipation was too rapid to allow achievement of the risk threshold voltage.” It is a partial answer to overcome the problem, but it is a poor solution if the test method cannot be used for the characterisation of the best state-of-the-art ESD garment materials. There is little to do with the 20 ms initial delay, but there could be other possibilities to modify the method so that it could be used for the characterisation of all ESD garment fabrics. At the minimum, some other criterion than the time to 10% of the maximum surface potential must be used.

### 5.3.2.2 Charge decay time according to prEN 1149-3, method 1 (triboelectric charging)

In the method test materials are charged by rubbing against cylindrical rods mounted on a vertically running slider, Fig. 8. The electrical field strength from the charge generated on the test material is observed and recorded using an electrostatic fieldmeter connected to a graphical recording device. The standard draft [34] specifies two materials for the charging rods: aluminium and dissipative HDPE (high density polyethylene). The test sample is grounded at one end of the sample. The test is done for samples made in the warp (or
machine) direction and for samples made in the weft (or width) direction. Charge decay is defined as the time taken for the indicated field strength to decay to $E_{\text{max}}/2$, i.e. $t_{50}$. Also the maximum electric field strength after triboelectric charging, $E_0$, and the electric field strength 30 s after $E_0$, $E_{30}$, are reported. The principles of the method and test set-up are described in detail ref. [34].

![Diagram of triboelectric charging test method](image)

**Figure 8** Example of an equipment for triboelectric charging test method according to prEN 1149-3: (1) fieldmeter, (2) fixed clamp, (3) test specimen, (4) start position of slider, (5) slider in end position, (6) guide rail, (7) tensioning device (weighted clamp), (8) cylindrical rods.

Tests were performed at two laboratories having dissimilar test set-up constructions (both still in agreement with prEN 1149-3). The correlation of the charge decay times between the two laboratories was satisfactory. There was no remarkable influence of the type of the rods on the charge decay.

A major disadvantage of the method is related to the approximately 0.1 s delay between the charging of a sample location and the moment when the measuring field instruments can measure the charged location. The fast processes in heterogeneous Type B fabrics have already decayed during that time. For homogeneous materials and Type A heterogeneous materials this is not a serious drawback, but for those materials there are simpler ways to evaluate the charge dissipation capability of the material. Therefore, we are not recommending the method as a general charge decay test method for ESD fabrics. The method, however, is useful for the characterisation of chargeability of the material, as will be discussed in Chapter 5.3.3.
5.3.2.3 Charge decay time according to prEN 1149-3, method 2 (induction charging)

In the method charging of the test specimen is carried out by an induction effect. Immediately under the test specimen, which is horizontally arranged, a field-electrode is positioned, without contacting the specimen, Fig. 9. A high voltage is rapidly applied to the field-electrode. If the specimen is conductive, or contains conducting elements, charge of opposite polarity to the field-electrode is induced on the specimen. Field from the field-electrode which impinges on the conducting elements does not pass through the test specimen and the net field is reduced in a way that is characteristic of the material under test. This effect is measured and registered behind the specimen with a suitable field-measuring probe. As the amount of induced charge on the test specimen increases, the net field registered by the measuring probe decreases. It is this decrease in the field that is used to determine the half decay time $t_{50}$ (specified in the same way as in the prEN 1149-3 tribocharging method as the time taken for the field strength to decay to $E_{\text{max}}/2$) used for the characterisation of charge decay of the material. The principles of the method and test set-up are described in detail ref. [34].

The tests were performed at two laboratories. There was good correlation of the results. All test samples with conductive elements had a very fast initial decay ($t_{50} < 0.1$ s). The time response of the method is fast, about $30 \mu$s (due to the rise time of the induction voltage), which allows the measurement of also the fast charge decay processes of the materials. Thus the method is potentially suitable for the correct characterisation of all types of ESD garment fabrics. This is a major benefit of the method. It is also possible to reduce information on the resistance of the conductive path (i.e. conductive fibres) from the charge decay curves. The measurement gives at the same time information to evaluate the electrostatic shielding performance of the fabric. That is discussed in Chapter 5.3.4.

A major hole of the method is that comparability of the results to those done by tribocharged samples is not yet shown. In heterogeneous samples the charge is generated differently on or in the material by induction and triboelectric charging. In the induction charging, the charge movement can happen anywhere in the conductive elements of the fabric. It cannot distinguish between what happens in the volume of a material and at its surface. It is not clear how this will influence on the results. It may appear that the relevancy of the method as a charge decay test is not high for end-users, if the correspondence of the charge decay behaviour results to those of surface charge generated by rubbing is poor. A study of that is in progress.
5.3.2.4 Charge plate monitor contact charging method (VTT-method)

The method is based on the application of charge plate monitor (CPM). A sample of fixed dimensions (width and length) is placed on the metal plate of the CPM, Fig. 10. One end of the sample is charged, at first, to a predetermined voltage using the CPM (or alternatively metallic plate + insulator + high-voltage (HV) power supply). Then the charging plate is disconnected from the power supply and the other end of the sample is grounded using an electronic HV switch and the voltage of the charged region is monitored as a function of time by the field meter of the CPM or by an external field meter or by a non-contact electrostatic voltmeter above the sample. In order to guarantee good electrical contact between the charging electrode and the sample, non-conducting and low-charging plate should be used above the sample as a weight. A PC can be connected to the field meter for the recording of charge decay curves, or alternatively one could rely just to the time counter of the CPM. For more details of the method see ref. [35].
Experiments were performed only at VTT so a comparison between different test houses was not done. According to the results the method is suitable for homogeneous and Type A heterogeneous fabric samples. However, for these materials the method does not give much additional information with respect to the standard point-to-point resistance measurements. For heterogeneous Type B fabrics the method characterises, in principle, only the conductive path of the material. There is no correlation to tribocharging methods, where the behaviour of the whole sample surface is taken into account. The contact charging method, however, characterises correctly the practical situation where the garment is really charged by an accidental contact to a charged electrode. In those heterogeneous fabrics where the conductive elements are buried (such as core conductive fibres) the method actually charges the test samples by induction – not by contact. For those samples the method is similar to the prEN 1149-3, method 2 but is less precise.

5.3.3 Chargeability

Chargeability of a material in triboelectric charging is one of the key factors influencing the ESD protective performance of a garment (Table 1). There are several laboratory and national standard test methods for the chargeability of fabrics. In the ESTAT-Garments project we have paid the main attention to two methods: prEN 1149-3, method 1 [34] and JIS L 1094:1997 “Frictionally charged electricity-amount measuring method” [37]. The Japanese JIS method, although originally at fabric level, could be applied also for full garments. The prEN 1149-3 method is in increasing favour in Europe and will likely become a new standard test method in a near future in the EN 1149 series.

5.3.3.1 prEN 1149-3 method 1

The method description was already given in Chapter 5.3.2.2. When considering the chargeability of the material, the focus is in the maximum electric field strength after triboelectric charging, $E_0$. The method does not give the absolute maximum triboelectric charging of the fabric but a tool to compare the chargeability of different fabric materials in a repeatable way. Sometimes, for instance, when applying a greater rubbing force or when using a different rubbing material, the test specimen may become more highly charged than in
tests following the prEN 1149-3 procedure. The repeatability and reproducibility of tribocharging tests are never at the same level as those of resistance measurement, but in the prEN 1149-3 method they are in a satisfactory level. Chargeability of different materials can be compared well by the tests.

The major weakness of the method concerns the rubbing partners. Currently there are two rubbing materials specified in the standard draft: aluminium (Al) and electrostatic dissipative high density polyethylene (HDPE). In the triboelectric series aluminium is about in the middle and polyethylene close to the lower (negative) end of the series. There is no rubbing partner at the upper (positive) end of the series. We included in the studies, in addition to the Al and HDPE charging rods, also charging rods made of electrostatic dissipative polyamide (PA). All the test fabrics were charged to essential higher level ($E_0$) by the polyamide rods than by Al- or HDPE-rods. The Al-rods resulted typically in the lowest $E_0$ values.

Minor weaknesses of the method are related to the measurement of the electrostatic field due to charged sample surface. At first, there is the 0.1 s delay after the charging before the measuring field instrument can measure the charged location. Due to the delay the true maximum is not measured. When characterising garment fabrics for electronics industry, this is not a problem. Within 0.1 s a tribocharged garment piece cannot be brought in practice sufficiently close to ESDS to create a risk. In flammable atmospheres the situation is different. There the charged person wearing the garment can be at the risk environment already at the moment of tribocharging. Secondly, the measurement window (cone) is too large with respect to the sample size covering not only the sample but also environment around the sample. Therefore VTT has adopted a modification of the method where the measurement is done by non-contacting electrostatic voltmeter at the distance of 25 mm from the sample surface and a correction (calibration) factor is used to correct the error due to the changed distance.

### 5.3.3.2 JIS L 1094 Frictionally charged electricity-amount measuring method

JIS L 1094:1997 is a Japanese Industrial Standard “Testing methods for electrostatic propensity of woven and knitted fabrics” including several test methods [37]. In the “Frictionally charged electricity-amount measuring method” a piece of fabric is placed on a metal plate covered with polyamide or a polyacrylic fabric and lain on a wooden place attached with a plastic bar from the sleeves, Fig. 11. The sample is rubbed five times at the rate of one trial per second with a PVC rubbing bar covered with a polyamide or a polyacrylic fabric by hand. Immediately after rubbing procedure the sample is thrown in a large Faraday cage and the electrostatic charge is measured. The procedure is repeated five times for both polyamide and polyacrylic charging fabrics. The results are given as charge per unit area ($C/m^2$).
The repeatability and reproducibility of the measurements are satisfactory, but not as good as in the prEN 1149-3 method. They could have been further increased by using motor controlled charging, like it was done in the prEN 1149-3 method 1. The major weakness of the method is related to the required movement of the test sample after the charging into the Faraday cage. That will take a few seconds during which charge decay can happen (even if the sample is not grounded) and the measured sample charging may not correspond to the true (maximum) chargeability of the material. Because of that and the progress in the standardisation of the prEN 1149-3 method, we did not consider the JIS L 1094:1997 Frictionally charged electricity-amount measuring method further as a potential IEC fabric level test method.

5.3.4 Electrostatic field shielding

Shielding of electrostatic fields from underlying garments is one of the main properties of ESD protective garments used in electronics manufacturing industry. prEN 1149-3 method 2 [34] provides an efficient tool for studying that at the fabric level. The measuring procedure is as described in Chapter 5.3.2.3, but the result analysis is specific for the shielding test.

Electrostatic shielding performance of a fabric is described by a shielding factor, $S$, defined by

$$S = 1 - \frac{E_R}{E_{100}},$$

(4)

---

2 Electrostatic field shielding in the context of this work should not be confused with ESD shielding in the context of ESD protective packaging. ESD shielding packaging must protect the device within the package against direct ESD currents as well as external electrostatic fields. The measurement of shielding properties of packaging are defined in terms of reduction of the energy experienced by the device as the result of an externally applied HBM pulse.
where $E_{100}$ is the initial electric field strength (without a sample) and $E_R$ is the residual electrostatic field due to electrostatic shielding. $E_R$ is illustrated in Fig. 12, which shows induction charging profiles for metallic, core-like and homogeneous fabric materials [8]. The shielding effect of the sample is not immediate and the responses are classified as 3 types – metallic, core like and homogenous. Materials that have a fast response with no initial peak are classified as metallic-like. Core-like materials show an initial peak $E_p$ that quickly decays within 30-50 µs to a residual value $E_R$. A “field penetration” figure of merit $E_R/E_{100}$ is defined, where $E_{100}$ is the initial field strength. The electrostatic shielding factor approaches 1 when $E_R$ approaches 0. The method is suitable for all types of materials. Homogeneous normal clothing fabrics show no shielding effect. For heterogeneous materials the shielding value depends on the conductivity of the conductive fabric components and the grid density of the conductive fibres.

![Figure 12. "Induction charging" profiles showing metallic, core-like and homogenous material decay profiles [8]](image)

The prEN 1149-3 test gives a conservative value for the electrostatic shielding. With inhabited garments made of the fabric, electrostatic field of the charge laying on clothing is partially suppressed by the direct coupling to wearer’s body. This effect is not included in the prEN 1149-3 method.

5.3.5 Capacitance loading

Capacitance loading method by J. Chubb is a relatively new, not yet routine method with a full name of “Test method to determine the limitation of surface potential created by electrostatic charge retained on materials” [4,38,39]. With regard to Table 1, it focuses on the voltage suppression effect, although the correspondence is not one to one. The capacitance loading method is based on the fact that fabrics do exhibit a relationship between surface charge and voltage and therefore have the characteristics of capacitance. An absolute expression of capacitance in the true sense is not possible since the fabric may be non-homogenous and part of the charge resides on non-conducting material surfaces. To a device or sensor sufficiently far from the surface the effects of an average charge and potential is experienced. One could use the relative expression that Chubb has defined as capacitance loading, CL. Capacitance loading (CL) is defined as the ratio of “capacitance” seen by a charge on the tested fabric to that on an ideal dielectric. CL is calculated from
\[
CL = \frac{Q_{\text{tot}}}{V} \frac{V^*}{Q^*_{\text{tot}}},
\]

where \(Q_{\text{tot}}\) is the total charge deposited on the tested sample surface, \(V\) is the initial peak voltage on the sample surface created by the charge deposited, \(Q^*_{\text{tot}}\) is the total charge deposited on a thin dielectric material used as the reference sample, and \(V^*\) is the initial peak voltage on the dielectric reference material. An IEC 61340-2-1 corona charging equipment can be used for the measurement of CL after it has been modified for the measurement of the total charge deposited on the sample under test. We used commercial JCI155 and JCI176 devices in the tests [40]. For more details, see the original references [4,38,39].

The CL is not a single valued constant for all materials. For homogeneous fabrics, such as 100% cotton, the CL value is about independent on the amount of deposited charge. For heterogeneous fabrics containing conductive threads, the CL of a given material increases linearly with the quantity of charge deposited [39]. In order to overcome the problem, it has been proposed to measure the CL at different \(Q_{\text{tot}}\) and to mathematically extrapolate the CL at \(Q=0\) [39]. It is our experience that this extrapolation is not always easy because the scattering of single CL \(Q_{\text{tot}}\) shots can be relatively high.

Another question related to the method is, how to interpret results correctly? That is, how to assess the garments (garment fabrics) ability to protect the electronics from ESD failures by using this method. High CL value for a fabric is related to high voltage suppression, which is a good, desired property. On the other hand, a high CL fabric could store much charge and create a possible risk of direct ESD, which is an undesired property for an ESD garment and garment fabric.

The capacitance loading method is another tool that can be used alongside other measurements to gain a fuller picture of how fabrics/garments behave. For garment fabrics with core conductive fibres, capacitance loading alone can prove useful. If surface voltage is suppressed to a low enough level there is no possibility of an air discharge occurring and field induced failures may also be prevented. The only way in which energy can then be transferred from the garment fabric to a device is by direct conduction which will be very minimal from a core conducting fibre. On the other hand, if we consider a fabric with stainless steel fibre, there is the possibility of significant energy being transferred by conduction if the conductive fibres are not effectively grounded. The combination of high capacitance loading and low resistance should be avoided in garments in order to minimise the ESD risks.

In summary, the capacitance loading method has a potential for a future standard method but more experience with a broader range of fabrics is needed before the value of the method can be fully assessed. Important question is that is it possible to predict surface voltages on inhabited ESD garments based on CL-\(Q=0\) values of the garment fabric? Holdstock et al. have made the first attempts to do that [39], but much more work is required before we can reliably answer to the question.

5.3.6 Summary of the fabric tests

Main results of the evaluation of existing fabric level tests are summarised in Table 4.
<table>
<thead>
<tr>
<th>Test parameter</th>
<th>Test method</th>
<th>Assessment for practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>surface resistance/</td>
<td>IEC (EN) 61340-5-1 (EN 100015-1) EN 1149-1</td>
<td>Suitable for homogeneous materials and heterogeneous materials type A (conductive/dissipative layer outside), for heterogeneous materials type B1 only in connection with other methods. <strong>Unsuitable</strong> for type B2 materials</td>
</tr>
<tr>
<td>resistivity</td>
<td></td>
<td><strong>Suitable</strong> for homogeneous materials and heterogeneous materials type A (conductive/dissipative layer outside), for heterogeneous materials type B1 only in connection with other methods. <strong>Unsuitable</strong> for type B2 materials</td>
</tr>
<tr>
<td>vertical resistance</td>
<td>EN 1149-2</td>
<td>Universal for all materials, no direct importance for the ESD assessment of outer clothing</td>
</tr>
<tr>
<td>charge decay</td>
<td>IEC 61340-2-1 (corona charging)</td>
<td>Suitable for homogeneous materials and heterogeneous materials type A (conductive/dissipative layer outside) <strong>Potentially suitable</strong> for heterogeneous materials but not in the present form (no fast decay). A modification is required.</td>
</tr>
<tr>
<td></td>
<td>prEN 1149-3 method 1 (tribocharging)</td>
<td>Suitable only for homogeneous materials and heterogeneous materials type A (conductive/dissipative layer outside), [but resistance much more simply] <strong>Unsuitable</strong> for all other heterogeneous materials (no value for fast decay) But suitable for the assessment of &quot;chargeability &quot; by tribocharging</td>
</tr>
<tr>
<td></td>
<td>prEN 1149-3 method 2 (induction charging)</td>
<td>Potentially suitable for all types of materials discrimination between fast and slow decay (e.g. possibility to quantify the &quot;Resistance of the conductive path&quot; and the resistance of the basic material), but comparability to tribocharging to be shown</td>
</tr>
<tr>
<td></td>
<td>charge plate monitor/contact charging (VTT’s method)</td>
<td>Suitable only for homogeneous materials and heterogeneous materials type A (conductive/dissipative layer outside), [but resistance much more simply], for heterogeneous materials type B1 and B2, in principle, only measuring the conductive path (for B2 via induction effect)</td>
</tr>
<tr>
<td>chargeability</td>
<td>prEN 1149-3 method 1 (tribocharging)</td>
<td>Universally suitable for all types of fabrics, but the method has to be revised in order to include a rubbing partner at the upper (positive) end of the triboelectric series (e.g. polyamide)</td>
</tr>
<tr>
<td>electrostatic shielding</td>
<td>prEN 1149-3 method 2 (induction charging)</td>
<td>Universally suitable for all types of materials, homogeneous &quot;normal&quot; clothing fabrics show no shielding effect, for heterogeneous materials shielding value determined by the grid density and conductivity of the conductive fabric components</td>
</tr>
<tr>
<td>capacitance loading</td>
<td>J Chubb’s method, based on modified IEC 61340-2-1 (corona charging)</td>
<td><strong>Probably suitable</strong> for heterogeneous type B1 and B2 (very small own data base), empiric correlation with tribocharging; type A yet not own basic for assessment, correlation to garment test still unclear, also questions about reproducibility</td>
</tr>
</tbody>
</table>

**Table 4** Summary of the evaluation of existing test methods for ESD fabrics
6 Evaluation of existing test methods for garments

6.1 Selection of methods and test garments

It is important to distinguish between fabric garment level tests. From the electrostatic point of view the difference between ESD fabric and uninhabited ESD garment is the effect of the seams. That is

\[
\text{Garment} = \text{fabric} + \text{seams}
\]

Thus the measurement of electrical conductivity across a seam is an important part of garment level tests. The influence on the ESD protective performance of the garment, of a grounded operator wearing the ESD garment, is so great that the protective performance can be studied in a realistic manner only with inhabited garments. Unfortunately, this situation would decrease at the same time the repeatability and reproducibility of test results. Measurement uncertainty at garment level with inhabited garments is always higher than that of fabric level tests due to increased human factors at garment level.

We made a survey of existing garment level test methods for ESD protective garments. When selecting test methods to a deeper analysis, the preference was given to existing IEC and ANSI/ESD standard test methods and those laboratory test methods which are widely used in national level in Europe. An initial preference was also for methods where the garment charging was by rubbing, because this is the case of the most concern in practice. The garment level test methods selected for the evaluation of existing test methods are listed in Table 5. Main results of the evaluation are given in Chapter 6.2. Like in Chapter 5, we will give in Chapter 6.2 a brief method description for all other than existing IEC or ANSI/ESD standard test methods, in which case a reader is referred to the original standards for more details.

It was decided to perform the tests with modern ESD protective materials which are known to be the most challenging from the electrostatic testing point of view. The selection of garment materials was done using the experience from fabric level tests. The selected garments included surface, core, and hybrid conductive threads in pure polyester base fabric. The classification of garment fabrics to homogenous fabrics and different types of heterogeneous fabrics, done in Chapter 5.2, is valid and plays an important role also at full garment level. Accordingly all the selected garments have Type B heterogeneous fabrics, according to the classification of Table 3.
Table 5  Existing garment level test methods selected for the comprehensive studies of the ESTAT-Garments project

- Resistive methods of IEC 61340-5-1
- Resistive methods of ESD STM2.1
- VTT’s method for the measurement of charge decay time of ESD-protective clothing
- SP Method 2175 “Measurement of charge decay time of ESD-protective clothing”
- STFI test method No. PS 07, version 01/03Rev. A “Test method to determine the body potential and the charge transfer by wearing of electrostatically dissipative protective clothing” (charge transfer – garment test)
- Shirley method 202 “Test method for measuring static electricity generated when removing garments from the human body”
- JIS L 1094:1997 “Frictionally charged electricity-amount measuring method”

6.2 Results of the evaluation

6.2.1 Resistive methods of IEC 61340-5-1 and ESD STM2.1

Resistive methods of the both major standards, IEC 61340-5-1 [13] and ESD STM2.1 [41], for full garments measure point-to-point resistances and/or resistance to a groundable point when the garment provides such a groundable point. In the IEC-standard it is said that care should be taken to include, where applicable, one seam between the two measuring electrodes. The ESD STM2.1 says that point-to-point test is intended to test the electrical resistance between any two points on the garment, which may include the electrical resistance across the seams of the garment.

The point-to-point resistance measurements in both standards are done for a garment under test laying on an insulating support. There are minor (in practice negligible) differences in the electrodes used in the point-to-point tests. According to IEC 61340-5-1, Appendix A.3, the measurements are typically taken from sleeve-to-sleeve, sleeve-to-hem (or leg), across back piece for 30 cm distance between the electrodes. The measurement voltage is typically 100 V. ESD STM2.1 describes a different arrangement for sleeve-to-sleeve resistance measurement, where the sleeve-to-sleeve measurement is done for garments hanging from each sleeve with electrically isolated, stainless steel clamps acting as electrodes. The purpose of the sleeve-to-sleeve method is to test the integrity of the electrical resistance across the seams of the garment.
According to the results of Chapter 4.2, resistance (or resistivity) is a key factor for most parameters important from the ESD protective performance point of view of ESD garments. But in most cases the relevant resistance, in the case of modern ESD garment material, is the resistivity of the conductive threads, not the overall resistivity of the material. The resistivity of conductive threads has a direct influence on peak ESD current, on charge transfer in an ESD, on the rate of charge dissipation of the garment and garment material by conduction and induction effects, on the electrostatic shielding property of the material and also on the voltage suppression in full garment system. The resistivity of the base fabric has a significant influence only on the charge dissipation by conduction. The resistance over garment seams is important, when each garment piece is not in a direct contact to ground, for the rate of charge dissipation as well as for the amount of retained charge as a possible source of direct ESD.

The electrodes used in the resistive methods of IEC 61340-5-1 and ESD STM2.1, however, do not measure a specific resistance of the conductive threads or the base fabric, but an overall resistance over a large contact area. In the case of ESD garment material that includes conductive threads and more or less insulating base fabric. Even more serious is the problem that good electrical contact between the electrode and the targeted subject (e.g. conductive threads) is not guaranteed. For example, in the case of core conductive threads the measuring electrode will not be in contact with the conductive fibre but with the insulating surface of the conductive threads. Electrical contact between the electrode and the conductive threads can be poor also with surface and hybrid conductive threads when the conductive fibres are not exactly at the fabric surface due to surface roughness, which can easily happen not only for used garments but also for new garments.

For homogeneous materials resistance measurements are the best way to evaluate the ESD protective performance of the material or product. The measurement is simple to perform, reproducibility is high (when $R<1\times10^{10}$ $\Omega$), and it covers most of the factors influencing the protective performance of the material. However, when the point-to-point or sleeve-to-sleeve resistance of the garment is $R > 1\times10^{10}$ $\Omega$, the influence of external disturbances and the leakage current of instrumentation wiring on the measurement result becomes easily so dominant that reliable measurements can be done only in specialised laboratories, not in the field.

For inhomogeneous (especially Type B) materials the situation is no more straightforward. The measured resistance may not correspond to the correct resistance that must be controlled. The most serious issue is that the actual conductive element of the material may not be contacted by a measuring electrode, which would directly lead to misleading results. A product may be rejected for inappropriate reasons. For garments having core conductive threads (Type B2), a proper electrical contact between the conductive elements and the measuring electrodes would inherently be never realised. The contact may be poor also with other types of modern conductive composite threads.

As a conclusion, the point-to-point and sleeve-to-sleeve resistive methods of IEC 61340-5-1 and ESD STM2.1 do not satisfactory well characterise any parameter controlling the protective performance of modern ESD garments. A garment may be rejected by inappropriate reasons when the point-to-point or sleeve-to-sleeve resistance measurements are used. Vice versa, on the other hand, is quite unlike. If a garment passes the resistance tests, the risk of ESD failures to ESD sensitive devices with reference to garments is small, supposing that the garment is correctly used and grounded and that the garment fabric structure is correct (that is, sufficiently small grid size of the conductive threads).
The measurement of the resistance to a groundable point is a useful measurement for all other than Type B2 heterogeneous (core conductive) garments. The measurement has value in verifying effective grounding of such materials that require it. The measurement should include, at least, one seam in the current path in order to test the integrity of the electrical resistance across the seams of the garment, and it should be done from every principal garment panel. Not all garments do have a specific groundable point. Therefore, the measurement should be modified to give directly a resistance to ground, preferably for inhabited garments, of all garments which are intended to be grounded in use. The measurement should be done from every principal garment panel.

ESD garments are sometimes used in electronics industry also in works where electrical safety issues are important or even critical. The test methods of IEC 61340-5-1 and ESD STM2.1 (point-to-point resistance and resistance to groundable points) are right methods to evaluate the electrical safety issues of the garments. The only comment is that, when evaluating the electrical safety, the measuring open voltage should for ‘high resistance’ garments be higher than the 100 V specified in the standards, for example 500 V, to reflect the hazardous voltage levels likely to be encountered in practice. Or alternatively a ramp of test voltage up to a few kV could be used, like in the resistive signature method under development at Centexbel [42].

6.2.2 VTT’s charge decay method for full garments

VTT’s method for the measurement of charge decay time of ESD-protective clothing is based on the point-to-point or sleeve-to-sleeve resistance measurement arrangements of IEC 61340-5-1 and ESD STM2.1. An alternate name for the method is charge decay time from point-to-point.

In the method garment under test is charged using contact charging by one of the electrodes used in the resistance measurements to a voltage exceeding 1000 V. Then the sample is earthed through the other electrode, and the discharge time from 1000 V to 100 V is recorded. Measurements could be taken at the same locations as the point-to-point and sleeve-to-sleeve resistance measurements. It is important to include measurements over a seam in the tests to measure the charge transfer across a seam. The measurements could be done either in a flat or hanging garment.

VTT’s charge decay time measurements from point-to-point characterises the charge dissipation capability of full garment mainly by conduction. The method simulates the practical situation of garment charging by contact and charge migration to ground through seams. The method comes very close to the point-to-point or sleeve-to-sleeve resistance measurements of IEC 61340-5-1 and ESD STM2.1. The method works well for the characterisation of the ESD protective performance of garments made of homogeneous materials, but it gives only little additional information with respect to the resistance measurements. With inhomogeneous, modern composite textile materials, it faces the same problems as the resistive methods of IEC 61340-5-1 and ESD STM2.1.
6.2.3 SP Method 2175

The SP Method 2175 “Measurement of decay time of ESD-protective clothing” [43] is a laboratory method, which has, in practice, an unofficial status of national standard in Sweden. There are also companies outside Sweden who like their garments to be tested according to this method.

The SP Method 2175 is intended to verify that each panel of the garment, intended as protection for ESD-sensitive components in electronics manufacturing, has a connection to the ground. The method is a system measurement. The measurement is performed with the garment worn by a person, targeting that also other phenomena, such as charge spread out on the complete garment, voltage suppression appearing in real world situations, are simulated. The application of the charge is performed by transfer of a charge from a capacitor, charged to 550-600 V, to any fabric panel of the test garment, Fig. 13. If the garment is conductive or dissipative, the charge will spread over the complete garment and the voltage will be suppressed by the capacitance of the garment to the test person. 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. The test person is grounded through a wrist strap and, thus, the charge shall be drained away from the test garment. The decay time from 500 V to 100 V of the charging electrode is measured and reported.

The SP Method 2175 is a system method. The operator inside the garment has an important and very relevant function in providing real, worst case ground paths for charge,

Worst case ground paths in that sense that the charge is forced to flow across a seam. In practice a charged garment panel may have a direct contact to operator's skin or a contact to operator's body through sufficiently conductive undergarment. The garment panel may also have a groundable garment point without a necessity for a charge to flow across a seam.
corresponding to real situation in a work bench. The involvement of a person to the measurement circuit increases the uncertainty of measurement, but the reproducibility of results is still good (but not as high as in the resistance measurements). Charge migration from the charged garment to ground via the operator body is correctly included in the method. The method also includes the effect of voltage suppression (coupling of fields to the grounded operator body) to the charge decay, although the effect is not clearly distinguishable and the influence of it is not well reproducible. The method, however, could be easily modified so that the voltage suppression effect would be correctly included in a reproducible way in the test.

We can conclude that the method characterises well whether each panel of the garment has sufficient electrical ground connection in a practical, worst case situation where the charge has to flow from one panel to another, across a seam, to find a way to operator’s body. The method also characterises well the charge dissipation capability of the garment in real operation conditions when the charging is done through a contact with charged material. It remains unknown how well the case corresponds to situation encountered more frequently in practice – garment charging by rubbing (triboelectric charging). A method could be easily modified for those garments which are designed to be grounded through an external ground wire attached to a groundable garment point.

The garments with core conductive threads failed in the tests because of the insulating layer between the conductive fibres and the operator, which makes too high barrier for charge to overcome within an acceptable time. The problem is fundamentally the same as in the case of resistance measurements. The method is not applicable to garments which can not be inherently effectively grounded (to reach equipotential bonding of all system elements).

6.2.4 STFI test method No. PS 07

STFI method No. PS 07 “Test method to determine the body potential and the charge transfer by wearing of electrostatically dissipative protective clothing” is a new laboratory method developed for the characterisation of ESD protective clothing used in explosion dangerous areas [44]. Version “01/03 Rev. A” was used in the current studies of ESTAT-Garments. The initial purpose of the method is to determine the ignition risk of protective clothing, made from dissipative materials, due to possible dangerous electrostatic charging of the human person or the garment.

The test set-up and the procedure is sketched in Fig. 14. An operator is clothed in a specified undergarment (cotton) and in the protective clothing as outer garment. The outer garment is highly charged triboelectrically by another person rubbing with selected textile material (pure wool fabric or pure polyamide fabric) on the back of the operator. The body potential, which is caused due to the generated charge on the clothing, is measured by an electrostatic voltmeter. An earthed, specified ball electrode [45] is then (as soon as possible) approached to the charged area of the garment to measure possible charge transfer in types of spark or brush discharges by a fast storage oscilloscope. The operator is in turn earthed and unearthed. Ten parallel measurements are made both with the person earthed and unearthed. Between measurements, the tested garments are neutralised by an ioniser.
Figure 14  Procedures of STFI method No PS 07: Garment charging, potential measurement, and the initiation and measurement of a discharge.
The STFI charge transfer – garment test is a new test method and it has been originally developed to characterise protective clothing used in flammable atmosphere. For such purposes it seems to be very suitable. It focuses on the correct key parameters to control: charge transfer in a discharge, the surface potential of the garment, and the body potential. The method has also a great potential for the assessment of ESD garments used in electronics manufacturing industry, where the key parameters to control are peak ESD current, charge transfer in a discharge, and device charging due to electric field external to the garment.

The method, however, is not ready and would require better specification to achieve greater reproducibility than obtained now. The difference between the test results at two different test houses involved in the method evaluation was too high. That clearly indicates that all important parameters influencing the results are not controlled in a satisfactory way. The major source for the low reproducibility is the rubbing partner (fabric): it must be of the same fabric material to achieve reproducible results at different test laboratories. Small differences in the rubbing fabric were found to lead to large differences in the test results (in absolute values). Furthermore, the probes etc. used in the method have been designed for the evaluation of risks in flammable atmospheres. They may not be ideal for the assessment of risks in electronics manufacturing environment. And finally, acceptance limits with respect to the key parameters to control are not yet specified for garments used in electronics manufacturing industry.

The method has a great potential in characterising the ESD protective performance of those garments which cannot be effectively grounded. It is the most potential method for the evaluation of the ESD protective performance of core conductive garments. The method takes into account all critical factors and could be (if the current problems with reproducibility are solved) the only garment level method required for core conductive garments. For garments used in the handling of the most sensitive ESDS (grounded surface conductive garments) the STFI method would not serve alone. A suggestion of simple, potential, test protocol for all ESD protective garments is given in Fig. 15. Tests required would depend on the ESD protection level required (high protection level requires always effective grounding of all garment panels) and whether the garment is intended to be grounded in use or not. The SP Method 2175 would verify that each panel of the garment has sufficient electrical connection to ground (in addition to this it gives also other useful information on the key factors influencing the ESD protective performance of the garment). The STFI Method PS07 would evaluate the risks of direct ESD and field-induced ESD due to charged clothing. (Note! This protocol may not be the final suggestion of the project. It is just a proposal for further study and evaluation in the project.)

In summary, the STFI method No. PS 07 has potential for a test method to be used when assessing the ESD protective performance of garments used in electronics manufacturing industry. Some improvements for the method, however, are required to improve the reliability of the results and to modify the method for the specific needs of electronics industry. Acceptance limits for the garments used in electronics manufacturing industry have to also be specified. The method is suitable for all kind of garments, including those with core conductive fibres.
Is the garment intended to be grounded in use?

Perform modified SP 2175

Perform modified STFI PS07 (garment grounded or ungrounded according to design)

Yes

Figure 15. Proposal of a simple test protocol based on SP2175 and STFI PS07

6.2.5 Shirley method 202

The Shirley method 202 “Test method for measuring static electricity generated when removing garments from the human body” is a laboratory method of BTTG (British Textile Technology Group) [46]. In accordance with its title, the method specifies procedures for measuring the static electricity generated when garments are removed from the human body. The method is applicable to all types of garments. For reference purposes, standard under garments are specified.

In the test procedure the test subject (person) stands with bare feet on the metal base plate and is momentarily earthed to remove residual charge, Fig. 16. The Faraday pail shall also be momentarily earthed. Then the test subject removes the test garment and drops it into the Faraday pail taking care that the garment does not touch the outside of the pail. Measurements of body voltage and charge on the removed garment are recorded. The test procedures are done ten times in total. The procedure is repeated for each combination of test garments and
reference garments. In the ESTAT-Garments tests two different reference garments were used, the garments made of polyester and cotton.

Figure 16 Sketch of the Shirley Method 202: 1) Electrostatic voltmeter, 2) Recording device, 3) Faraday pail with charge measuring device (3a), 4) Metal base plate, 5) Insulating support.

The Shirley method 202 is focused on a major parameter to control in ESD protective clothing: chargeability of the tested garment by triboelectric charging. The method is simple and, besides a large Faraday cage, only basic electrical measurement equipment is required. Reproducibility of the results was also satisfactory good, taking into account that it is a tribocharging method. Comparability between results from different kinds of garment tests (coat, overalls, shirt), however, is not straightforward because the way of tribocharging (removing process of the garments) is not exactly the same. Also surface areas of different kinds of garments are not the same.

The major weakness of the method, if looking from the point of view of ESD garment evaluation, is that it simulates the situation strictly forbidden in ESD protective area (EPA). Simply from this argument, the method has no potential for an international standard characterising ESD garments used in EPA. On the other hand, it is a potential method for the characterisation of electrostatic properties of everyday clothing used in casual environment.
6.2.6 JIS L 1094:1997 “Frictionally charged electricity-amount measuring method”

The JIS L 1094:1997 method “Frictionally charged electricity-amount measuring method” [37] is originally for pieces of fabric, but it is applied also for full garments. The method presentation was given in Chapter 5.3.3.2. When applied to garments, a whole garment (instead of a piece of fabric) is charged on the rubbing stand.

The Japanese Industrial Standard method intends to evaluate the chargeability of the garment or, actually, garment material. Other factors related to the ESD protective performance of garments are not considered in the method. Reproducibility of the results was satisfactory (taking into account that it is a tribocharging method). For the needs of electronics manufacturing industry, different rubbing materials could be chosen. A major criticism of the method is that garment charging is measured only after a delay of a few seconds. Furthermore, it characterises a fabric, not garment, property. It would have a value at a garment level as a periodic test method, but it is too specific and complex for most production plants and laundries doing periodic testing of garments. The method is not considered for further consideration at garment level.

6.2.7 Summary of the garment tests

Main results of the evaluation of existing garment level tests are summarised in Table 6.
<table>
<thead>
<tr>
<th>Test method</th>
<th>Test parameter</th>
<th>Assessment for practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC (EN) 61340-5-1 ESD STM2.1</td>
<td>point-to-point and sleeve-to-sleeve resistance resistance to a groundable point</td>
<td>Suitable for homogeneous materials and heterogeneous materials type A (conductive/dissipative layer outside), for heterogeneous materials type B1 only in connection with other methods, Unsuitable for type B2 (core conductive) materials</td>
</tr>
<tr>
<td>VTT’s method for the measurement of charge decay time of ESD-protective clothing</td>
<td>charge decay</td>
<td>Suitable only for homogeneous materials and heterogeneous materials type A (conductive/dissipative layer outside), [but gives little additional information in respect to resistance measurement], for heterogeneous materials type B1, in principle, only measuring the conductive path. Unsuitable for type B2 (core conductive) garments</td>
</tr>
<tr>
<td>SP Method 2175</td>
<td>garment grounding charge decay voltage suppression</td>
<td>Suitable for garments with homogeneous materials and garments with type A and type B1 heterogeneous materials [some modification preferable] Unsuitable for type B2 (core conductive) heterogeneous materials</td>
</tr>
<tr>
<td>STFI Method PS07</td>
<td>direct ESD chargeability of worn garments electrostatic field external to worn garments</td>
<td>Potentially suitable for all types of garments, but the method has to be better specified in order to have better reproducibility of results.</td>
</tr>
<tr>
<td>Shirley method 202</td>
<td>chargeability</td>
<td>Unsuitable for ESD protective clothing Suitable for everyday clothing in casual environment</td>
</tr>
<tr>
<td>JIS L 1094:1997</td>
<td>chargeability</td>
<td>Suitable for all kinds of garment materials, but focuses on fabric not garment level properties.</td>
</tr>
</tbody>
</table>

Table 6  Summary of the evaluation of existing test methods for ESD garments
7 Development of new methods and modification need for existing methods

The current standard test methods characterises sufficiently well the ESD protective performance of garments made of electrically homogeneous fabrics or from heterogeneous fabrics with a homogeneous conductive or dissipative layer on the surface. For all other garments, indeed for the majority of state-of-the-art garments, they cannot provide elements for the correct evaluation of the ESD protective performance of garments. For garments with surface conductive fibres they may give valuable information, which is, however, insufficient alone in making correct conclusions. The current standard test methods are completely unsuitable for the characterisation of garments with core conductive fibres.

ESD garments where the conductive elements are core conductive threads are really the most problematic for the assessment of their true ESD protective performance. The conductive elements can not be easily contacted or grounded satisfactorily. Therefore, the garments typically fail verification tests (that may require good electrical contact) for inappropriate reasons. The principal charge dissipation mechanism in material having core conductive threads is typically different to the charge dissipation mechanisms of surface conductive threads (see Chapter 4.2). The charge dissipation performance of core conductive garments is mainly based on the corona discharge mechanism, the effect of which depends mainly on the structure of the conductive threads not on electrical parameters of the material. (The base fabric of a core conductive garment may have some charge dissipation capability in its own but the time constant is typically long.) In corona discharge, the corona current is quenched when the local electric field has decayed to a certain level. At that level the material still has quite a lot charge. The residual charge would hardly cause a direct ESD of such level causing failures to ESD sensitive devices, because of the high surface resistance of the conductive grid. The risks of direct ESD could be assessed by measuring discharges from charged fabrics. A method for that is under development in the ESTAT-Garments project. The method would naturally apply also to other types of fabrics. Instead of direct discharges, the electrostatic field external to the garment due to the residual charge may be strong enough to charge a nearby device by induction creating a risk of subsequent CDM type of ESD and potential failure of the device. That is not assessed by the present standard test methods for ESD garments.

The test methods considered in Chapters 5 and 6 were mainly methods suitable only for specialised laboratories. They may be too complex (or will require expensive investments on instruments) to be applied at production sites and in laundries. The exceptions are the current resistive standard test methods, which have other limitations discussed above. Thus there is a clear need for simple test methods for periodic testing of full garments. These periodic tests do not have to cover all the important parameters influencing the ESD protective performance of a garment, because the periodic testing is done for garments (garment types) which have already passed the higher level approval tests done at specified laboratories for new products to enter the market. The periodic test can focus only to those parameters which are the most critical in the particular application and/or which can be altered in use. Development of simple test methods for periodic testing is in progress in the ESTAT-Garments project. After development they will be critically evaluated.
Many of the existing methods discussed in Chapters 5 and 6 do also have a need for modification in order to better respond to the real need, which is to correctly evaluate the ESD protective performance of state-of-the-art garments and garment fabrics. In the fabric level methods, for example, the IEC 61340-2-1 charge decay test method based on corona charging has to be modified before it would be suitable for state-of-the-art heterogeneous ESD fabrics having conductive fibres in an insulating cotton, polyester or cotton-polyester mixture base fabric. The modification may included changes in the measurement procedure or to the acceptance criteria or both. The prEN 1149-3 tribocharging method needs (at least) a reselection of the rubbing partners, i.e. the charging rods. There should be a rubbing partner at both ends of the triboelectric series. With the prEN 1149-3 induction charging method, a comparability of results to tribocharging is not yet studied. Until that is not known, the suitability of the method for the evaluation of charge decay performance of garment fabric under realistic conditions cannot be fully assessed. Chubb’s capacitance loading method needs to be studied in more detail. The relevance of the method to end-user applications (i.e. correlation of fabric level results to inhabited garment performance) is still very unclear. Much more studies on that have to be done before the usefulness of the capacitance loading method can be fully evaluated.

At the garment level the situation is not different. The standard resistive test methods have to be modified to measure the resistance-to-ground also with those garments which do not have a specific groundable point. That would mean a system test with inhabited garments. The SP method 2175 requires some improvement to take the voltage suppression effect better into account. The STFI method PS07 needs to be better specified in order to increase the reproducibility of results to a satisfactory level. There are also open questions related to the discharge probe. The currently used probe is optimised for spark and brush discharges in flammable atmospheres. It is not initially clear whether the same probe is ideal for evaluating direct ESD threats to ESDS.

The modification work is currently in progress in the ESTAT-Garments project. After the modification work is completed, round robin tests will be performed with different kinds of state-of-the-art garments and garment fabrics and analysed. Recommendations of test methods for a future ESD garment standard and a possible ESD fabric standard (if a separate document) could be given in spring 2005 after the round robin tests are completed and reported.

Some of the potential methods under consideration have been developed for the characterisation of ESD protective clothing or fabrics used in flammable atmospheres. Accordingly, the recommended acceptance limits are related to the minimum ignition energy or charge of materials, gases, or dust. There are no recommended acceptance limits for ESD items. Furthermore, the acceptance limits of some existing methods for ESD garments and garment materials used in electronics manufacturing industry have to be reconsidered, in accordance with the recent progress in semiconductor technology. The setting of proper acceptance limits for the potential test methods under consideration is another major task of the ESTAT-Garments in progress and to be completed by the end of 2004.

There are also problems to be solved which are more general, not directly related to a specific method. One is related to the type of a garment or garment material under test: homogeneous or heterogenous, intended to be grounded (surface conductive) or non-grounded (core conductive) in use. Test methods that rely upon correct identification of the garment or fabric under test are not ideal as they are likely to be misinterpreted or misused by non-skilled users. A good example of that is the resistive methods of IEC 61340-5-1 [13] and ESD
STM2.1 [41], which are initially completely unsuitable for core conductive materials but are, in practice, used for them resulting in rejection of products for improper reasons. A solution to overcome the problem would be a clear marking of garment type according to standardised rules.

A second problem to be solved is related to the measurement of electrostatic field external to the garment vs. the actual risk threshold of ESDS. The risk threshold for damage is reached when an ESDS is exposed to an electric field exceeding a threshold level, such as 10 kV/m. Electrostatic field can be measured satisfactory well by a fieldmeter with a suitable size guard plate. A problem remains at what distance the garment or fabric evaluation test should be done in order to mirror the real risks and thresholds for damage. Secondly, most handheld ‘fieldmeters’ are actually set up to show surface voltage. Surface voltage (potential) would be more easy parameter to measure, but then the link to the real failure mechanisms of ESDS is strongly loosen or even totally lost. An IEC 61340-5-2 criterion [14] where a maximum surface voltage of 100 V is allowed on a fabric or garment surface would be too strict for \( V_{\text{HBM}}=100 \) V devices and would lead to rejection of proper ESD garments and fabrics for improper reasons.
8 Classification of garments

The purpose of ESD garments is to protect sensitive electronics from ESD failures or, at least, to minimise risks of ESD failures to sensitive electronics. The required protection level would vary a lot between different production lines and plants, depending on the sensitivity of the devices in production. Handling of ultrsensitive Class 0 or more robust Class 3 devices with HBM withstand of 4 kV gives very different requirements for ESD garment’s protective performance. Currently there are same criteria for all ESD protective garments. In the future there may be a need for different classes for ESD garments due to the diverse need of end-users, the classes depending on the sensitivity of ESDS to be protected and the relative humidity in the production plant. Also validation tests may not be the same for all categories. The idea is illustrated in Table 7. The numerical values etc. are just examples.

<table>
<thead>
<tr>
<th>Garment class</th>
<th>Targeted protective use</th>
<th>Required garment performance and structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 0</td>
<td>Ultrasensitive devices with &lt;100 V HBM withstand</td>
<td>High protection level; special recommendations for grounding, garment design, use etc.</td>
</tr>
<tr>
<td>Class 1</td>
<td>ESDS with ≥100 V HBM withstand</td>
<td>Normal protection level. Requirements for the electrostatic performance corresponding to typical state-of-the-art ESD garments</td>
</tr>
<tr>
<td>Class 2</td>
<td>ESDS with &gt;2 kV HBM withstand</td>
<td>Low requirements for the electrostatic performance, main attention to chargeability</td>
</tr>
</tbody>
</table>

The classification is based on the standard HBM, or alternatively, CDM withstand levels of ESDS that can be safely handled using ESD garments of the given class at a given relative humidity and temperature. The climate conditions could be, for example, 12 % RH, 23 °C (dry conditions) and 50 % RH, 23 °C (normal conditions). For each class there would be different electrostatic requirements of the garment performance, such as resistance to ground, chargeability, charge decay time, electrostatic shielding, etc. There could also be special requirements for the garment design, such as tight sleeves and special grounding point, and for the use of the garment, such as recommendations for normal clothing that can be used under the ESD garment. Because electrostatic properties of garment material depends on the humidity, it could be that a garment, which is classified as a Class 2 garment at 12 % RH, could be a Class 1 garment at 50 % RH. The garment must be classified according to the worst case expected operating conditions.

The proposal of three different categories of ESD protective clothing instead of one could be an answer for the diversified requirements of electronics manufacturers. The current IEC 61340-5-1 protection level (Class 1 garments) would satisfy most of the manufacturers. Manufacturers of ultrsensitive electronics may wish better protection level for their garments than what Class 1 would give. On the other hand, there are electronics manufacturers who are more concerned about electrostatic attraction and product contamination due to particulate emission than ESD. Their requirements may be fulfilled by a cleanroom garment whose ESD performance is only moderate (Class 2) but whose linting is low. Maximum ESD and contamination protection can be seldom provided by the same garment solution and, therefore, compromises in the protective performance have to be done.
9 Conclusions

The following parameters have been identified as the key parameters to control in order to minimise ESD failures with reference to garments (not in any priority order):

♦ Peak ESD current
♦ Charge transfer in a direct discharge to a victim device
♦ Induced device charging due to electric field external to the garment
♦ Device charging due to accidental rubbing against the garment

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

In the ESTAT-Garments project we have evaluated also several other existing, non-standard, test methods for garments and garment fabrics. Neither of them cover all the important aspects influencing the protective performance of modern ESD garments in electronics manufacturing environment. After a modification, a few of them could have potential as a new standard test method for ESD protective garments and garment fabrics.

There is a need for different level of test methods. There should be fabric tests and full garment tests. These could well emerge as different standard documents. Furthermore, at the garment level there should be an approval testing, which should cover all the important aspects influencing the ESD protective performance of the garment, and simple periodic testing, which can focus only on a few critical factors potentially altered in use. Ideally the methods would be the same for both approval and periodic testing, but that may not be a realistic target for modern ESD garments.

Currently there are 5-6 methods for fabrics and 3-4 methods for full garments for approval tests and a few simple methods for periodic tests under further consideration in the ESTAT-Garments project. The number of the methods is too high to be put forward as ESD fabric or ESD garment standards. Furthermore, there is partial overlap between the methods in the properties they characterise. Further work is required in order to select the minimum number of methods covering all the important properties and aspects related to the ESD protective performance of ESD garments and garment fabrics.
References


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