ESTAT Garments

IEC TC101 WG5 PT2 Meeting

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VTT

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ESTAT-Garments project

- European research project funded in part by the European Commission
- Duration: March 2002 - February 2005
- Project partners
  - VTT Technical Research Centre of Finland (FIN), Co-ordinator
  - University of Genova (I)
  - SP Swedish National Testing and Research Institute (S)
  - Centexbel (B)
  - STFI Sächsisches Textilforschungsinstitute (D)
  - Nokia (FIN)
  - Celestica (I)

ESTAT-Garments project

- The main goals of the project are 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
  - develop appropriate test methods for the characterisation of such ESD protective garments.

Background

- Requirements for the ESD protective clothing in electronics manufacturing industry are very diverse:
- Manufacturers handling very ESD sensitive devices require high ESD protective performance for the upper garments;
- For some manufacturers the primary concern of ESD garments is the linting performance (cleanroom garments), ESD being of secondary importantance.

⇒State-of-the-art garments are composites consisting of conductive/dissipative and insulating elements.

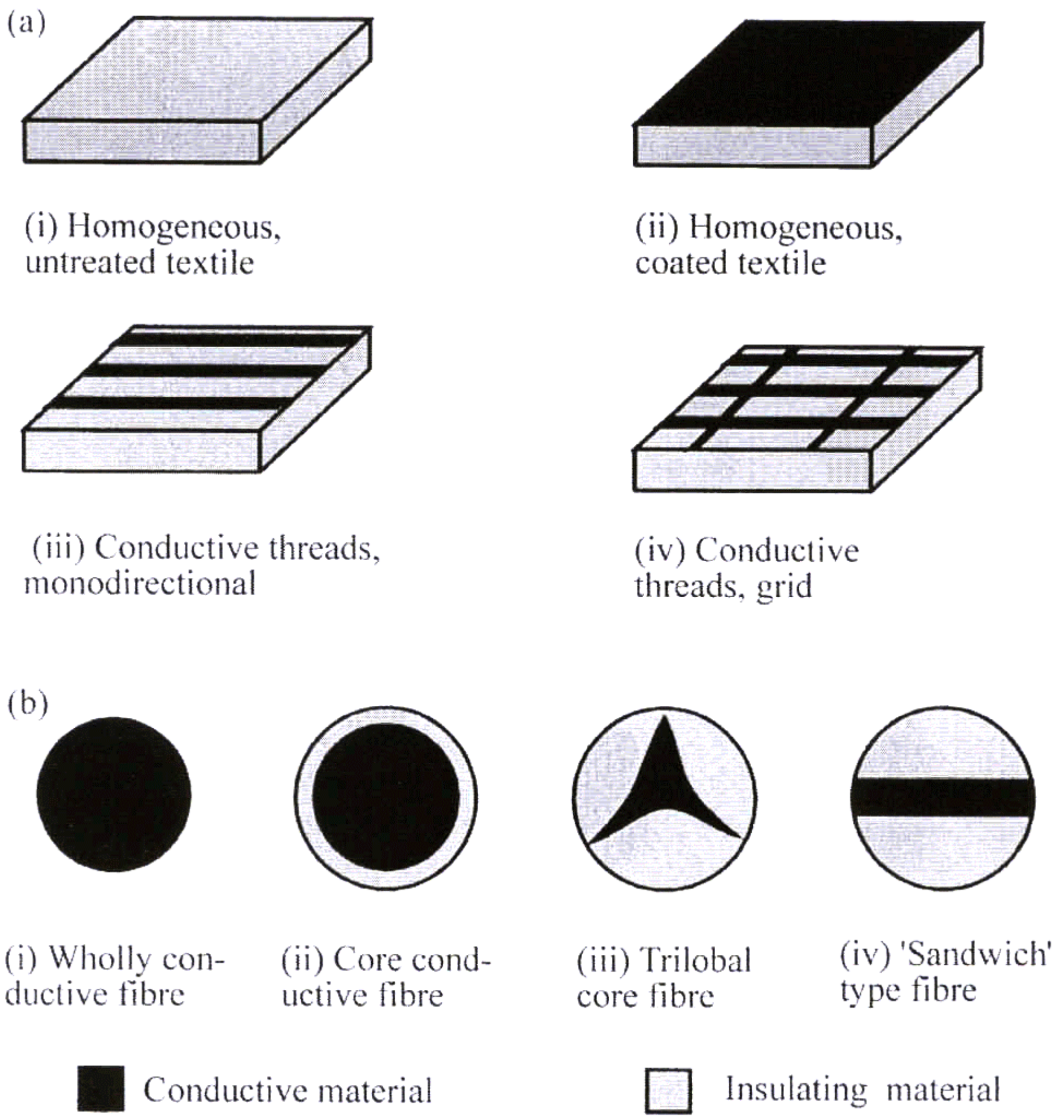
- Some ESD garments can be grounded while others are inherently non-groundable (garments with core conductive fibres).

⇒**GREAT CHALLENGE FOR STANDARDISATION WORK!**

Background

- There is a need of different kinds of tests
  - **Fabric** level tests
  - Full **garment** level tests
- There is a need of different level of garment tests
  - **Approval tests** for new products to enter the market
  - **Periodic field/audit tests** done for garments already in use
- Ideally all the requirements are covered by a single and simple test, such as resistance measurement.
- Due to the diverse requirements and diverse types of garments, this is not a realistic target.

Background



(a) Structures of homogeneous and heterogeneous textiles

(b) Structures of commonly used conductive fibres

Risks of ESD damage to ESDS with reference to garments

Risks of ESD damage to ESDS with reference to garments

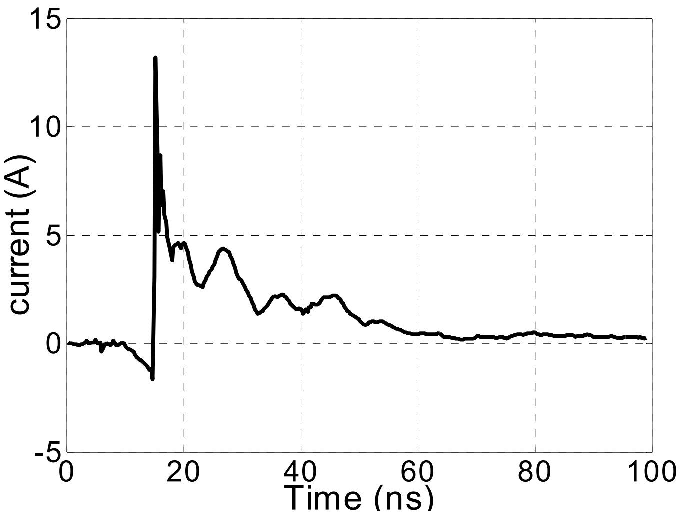
- **What causes device failure?**
- Devices can be sensitive to
  - **ESD energy** *(energy or power - depending on the discharge duration - both related to ESD current)*
  - **Voltage** *(typically an internal breakdown voltage, for example of a dielectric, and not the applied ESD voltage - threshold often related to device charging)*
- An ESD failure due to charged clothing can happen
  - by a **direct discharge** to a device
  - by **discharge from the charged device**
  - by **radiation**, i.e. an induced EMI due to ESD

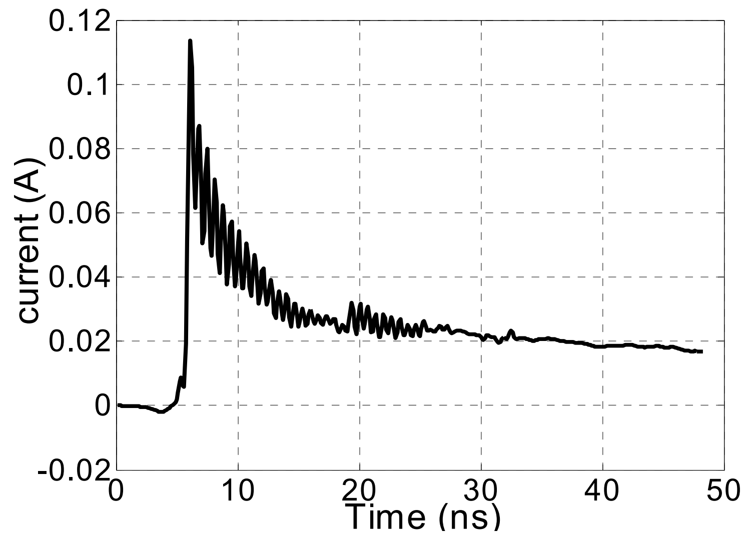
Risks of ESD damage to ESDS - Direct discharges

- Direct discharges may cause damage by charge injection to the device.
- Direct discharges with reference to garments are typically related to
  - **insulating surfaces of the garment fabric** (continuous area of > 20x20 mm, charged to >300 V).
  - **unearthed** (improperly earthed) conductive fibres and other **conductive elements of the garment** (ESD risks are strongly related to the resistivity of the conductive elements)
- Discharge waveforms will depend on the electrical characteristics of the ESD source and load. Usually they resemble the shape of HBM ESD (duration can be different).

Risks of ESD damage to ESDS - Direct discharges

- For example, a discharge from stainless steel threads (left fig.) has much higher peak current than a discharge from carbon based fibres (right fig).





- As many components are sensitive to discharge energy or power, which are related to discharge current, it seems reasonable **to place a threshold on peak ESD current** to control these aspects.

Risks of ESD damage - Device charging and CDM ESD

- A device may become charged with reference to garments and, after that, gets ground contact giving rise to CDM ESD.
- A device may charge by two principal methods:
  - **Accidental rubbing** of the package against the garment material may cause **charging by triboelectrification**
  - 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 may also experience **induced voltage stress**.
- The risk threshold is reached when the charge induced or generated on the component reaches the device CDM withstand voltage level.

⇒It seems reasonable to place **threshold on device charging**, which is applies also for voltage sensitive devices such as MOSFETs.

Risks of ESD damage - Device charging and CDM ESD

- Also an entire Printed Wiring Board (PWB) may become charged.
- Devices assembled on a PWB can be more easily damaged by ESD (Charged Board Model ESD) than at component level.

⇒While the IEC 61340-5-2 recommendation that "ESDS should not be exposed to electrostatic fields in excess of 10 kV/m" includes a significant safety margin for free V_{HBM}=100 V devices, the safety margin can become negligible when the device is assembled on a board.

Risks of ESD damage - Importance of grounding

- Most of the ESD risks associated with charged clothing are minimised by using ESD protective garments, where all garment panels and conductive elements are grounded satisfactory well.

⇒All parts of the garment shall be well connected and a path to ground should exist.

- Depending on which ESD safety level is required, exceptions could be allowed, particularly if humidity >40 % RH.
- NOTE 1: The use of non-grounded ESD garment with high surface conductivity may be a higher risk to ESDS than normal upper garments.
- NOTE 2: Core conductive garments cannot be adequately grounded due to its buried conductive elements.

One cannot conclude anything from the last statement about their potential value in ESD protective garments.

Risks of damage to ESDS - Conclusions

Normal clothing

- **Questions**
  - What potentials can be found on the normal clothing?
  - What is the peak current and the charge amount that can be extracted from normal clothing?

- **Answers**
  - We measured more than 3.5 kV_1 (surface potential on a garment) and 1.4 kV_2 (voltage induced on a device close to the garment).
  - We measured a peak ESD current of 0.8 A and transferred charge of 320 nC at 700 V.

- **Can this damage sensitive devices? - Yes**

Risks of damage to ESDS - Conclusions

The protective garment

- **Question**
  - What should the function of the ESD protective garment be?
- **Answer**
  - The protective garment should effectively shield the electrical field originating from the insulating parts of the operators normal clothing; and
  - The protective garment should prevent direct discharges from the operators normal clothing; and
  - The protective garment should not itself cause similar problems; and
  - The protective garment should be low charging by triboelectrification.

Risks of damage to ESDS - Conclusions

- The following parameters have been identified as the key parameters to control in order to minimise ESD failures with reference to garments
  - **Peak ESD current** from fabrics, conductive fibres, etc.
  - **Charge transfer** in a direct ESD to a victim device
  - Induced device charging due to **electric field external to the garment**
  - Device charging due to **accidental rubbing by garment**.
- Electrostatic evaluation of ESD protective garments and garment fabrics should address to the first three key parameters to control
- Open questions are the **protection levels and methods to correctly characterise the ESD protective performance of garment.**

Risks of damage to ESDS - Conclusions

- **Peak ESD current and charge transfer in a direct discharge** from charged fabric is largely determined by
  - the resistivity of conductive threads (which is not the same as the measured surface resistivity by the IEC 61340-5-1 method)
  - the grid density and grid structure
  - the amount of retained charge
  - the area of material discharged

Risks of damage to ESDS - Conclusions

- **Device charging due to electrostatic field external to the garment** is largely determined by
  - the **chargeability** of the garment fabric by triboelectrification
  - the **rate of charge dissipation** of the garment/garment material (charge decay) by
    - conduction mechanism
    - induction mechanism
    - corona mechanism
  - the **electrostatic field shielding property** of the garment material
  - **voltage suppression** due to coupling of fields to the grounded body of the operator

Evaluation of existing test methods for fabrics

Evaluation of test methods for fabrics

- A survey of existing test methods for the characterisation of the electrostatic performance of ***ESD garments and*** garment ***fabrics*** was done, covering
  - international standards
  - major national standards worldwide
  - a few commonly used industrial and laboratory methods without a standard status.
- Preliminary Screening of Methods based on former studies(SMT4-CT96-2079, etc.)

Evaluation of test methods for fabrics

- The following existing test methods for garment fabrics were selected for a comprehensive experimental evaluation
  - Resistive methods of IEC 61340-5-1 (surface resistance, point-to-point resistance)
  - Resistive methods of EN 1149-1 /-2 (surface resistance, vertical resistance)
  - Corona charging test according to IEC 61340-2-1 (5-1)
  - Induction charging test according to prEN 1149-3
  - Triboelectric charging test according to prEN 1149-3
  - Charge decay test by contact charging (VTT-method)
  - Capacitance loading test of John Chubb (corona charging)
- In this presentation the focus is in the most potential methods for a future IEC 61340 series garment/fabric standard

Electrostatically homogeneous vs. inhomogeneous

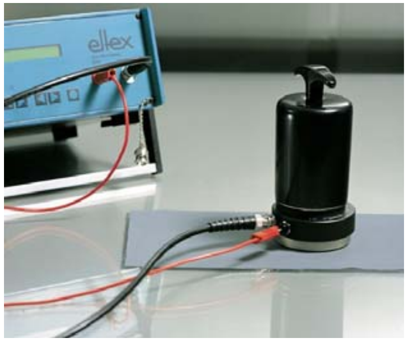
Electrostatically homogeneous material

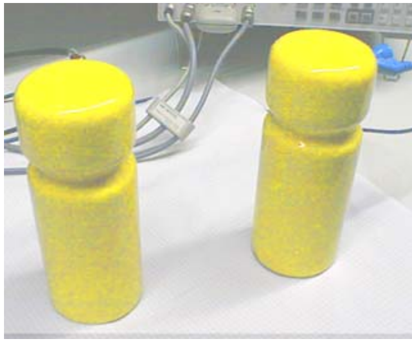
- consisting on a **uniform textile fibre material or a mixture of several different fibre materials**, which do **not have extremely high difference in the electric conductivity**

Electrostatically heterogeneous (inhomogeneous) material,

- consisting on **several components of materials** 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

Evaluation of test methods for fabrics





Resistive methods of IEC 61340-5-1

- For homogeneous materials, the best way to evaluate the ESD protective performance of the material or product -
  the measurement covers most of the factors influencing the protective performance of the material.
- Problems may arise when $R_s > 1x10^{10}\ \Omega$.
- For heterogeneous, *surface conductive* materials ***suitable only*** in connection with other methods; the measured resistance may not correspond to the correct resistance that must be controlled
- The resistive methods are ***not suitable*** for materials where the conductive elements are not directly in the surface, for example cleanroom garments with *core conductive* fibres.

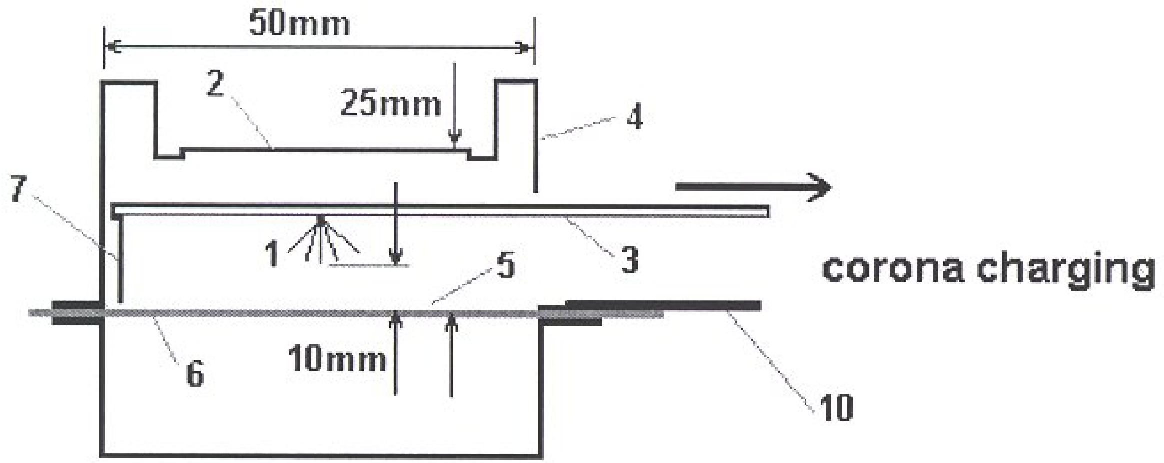
Evaluation of test methods for fabrics - charge decay methods

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

- In the method the charge is deposited by corona on the sample surface

⇒Good correlation to charge decay results with tribocharging techniques.

- The method is ***suitable for electrostatic homogeneous materials*** with sufficiently high resistance of about $\geq 10^9\ \Omega$.



Charge decay time according to IEC 61340-2-1 (corona charging method) … cont.

- For state-of-the-art heterogeneous ESD fabrics the test, done according to IEC 61340-2-1 or -5-1, may easily give false results on the ESD protective (charge decay) performance of fabric under test.

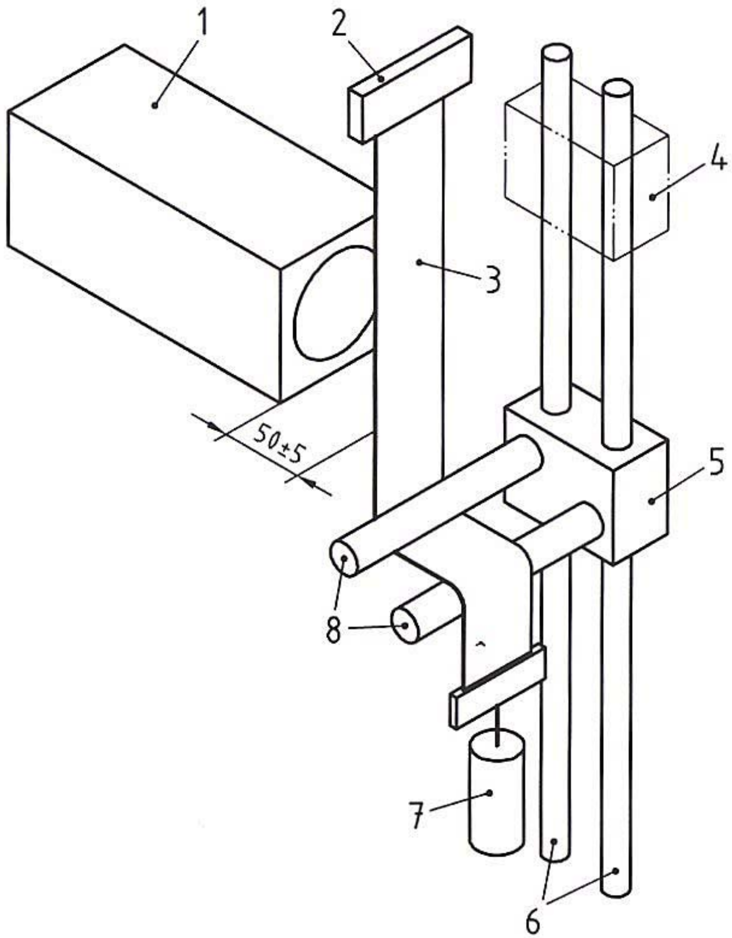
⇒Good ESD material may be rejected for improper reasons.

- The test partially (or fully) omits the fast decay component due to conductive fibres and overemphasises the influence of the insulating base material. (Ref. Holdstock's presentation at the 101/WG5 Kista meeting)

- The method itself is ***potentially suitable*** also for heterogeneous fabrics with surface or core conductive fibres ***but not*** in the present form.
  - A ***modification*** is required, and/or
  - The method should be used ***only in connection with other methods***, such as the Capacitance loading method.

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.
- Fabric under test is grounded at one end of the sample.
- Two rubbing materials are used:
    - Aluminium rods
    - Electrostatic dissipative high density polyethylene (HDPE)

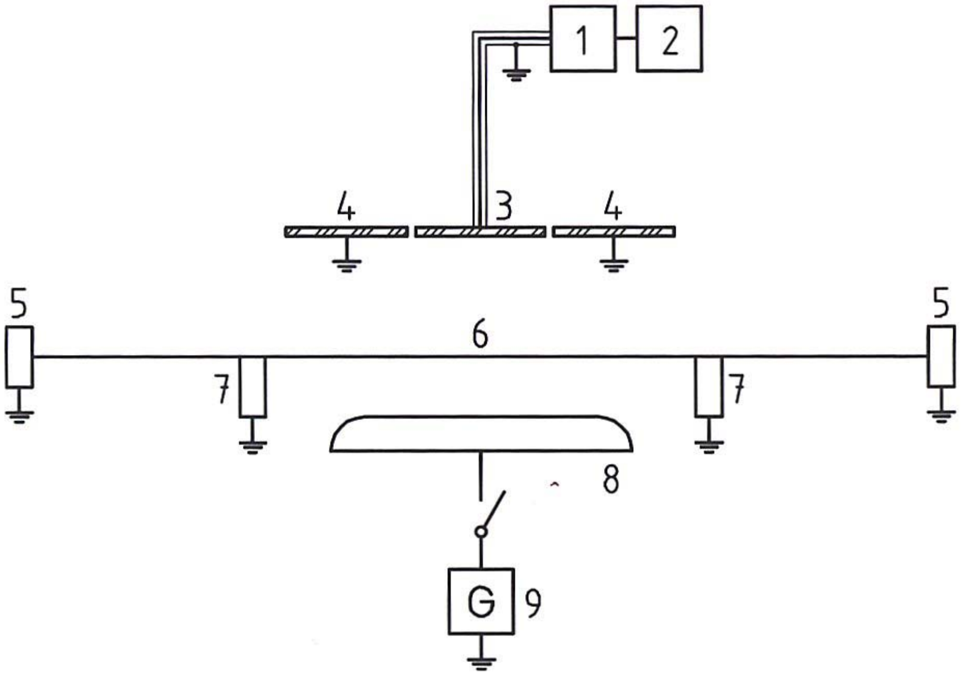


Charge decay time according to prEN 1149-3, method 1 (triboelectric charging) … cont.

- The method is ***suitable for*** the characterisation of ***homogeneous fabrics*** (but resistance measurement is much more simple).
- The method is ***unsuitable for*** the characterisation of charge decay in ***heterogeneous ESD fabrics*** with metallic or surface or core conductive fibres.
- The method omits the fast decay component due to conductive fibres and overemphasises the influence of the insulating base material.

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.
- As the amount of induced charge on the test specimen increases, the net field registered by the measuring probe decreases.
- This decrease is used to determine the decay time.



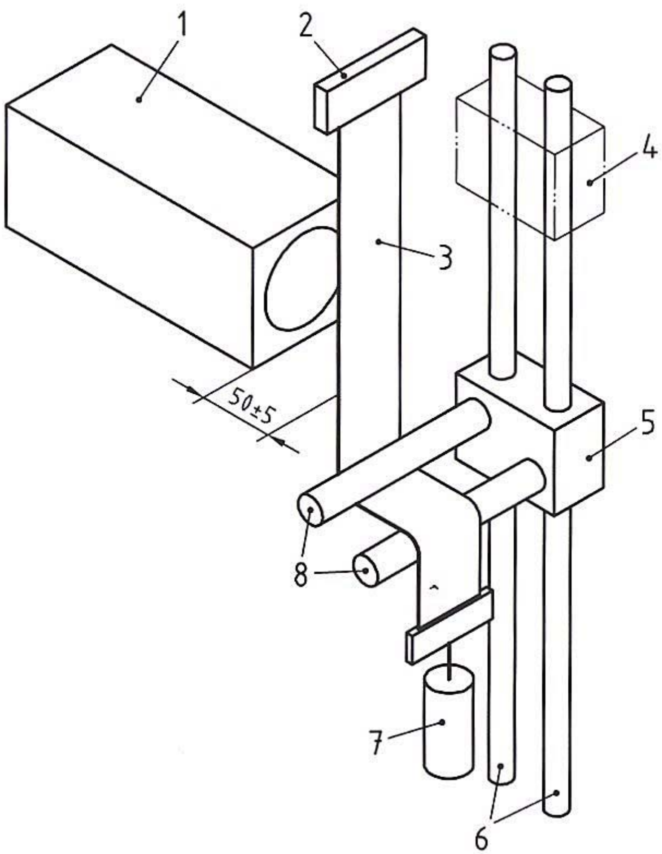
Charge decay time according to prEN 1149-3, method 2 (induction charging) … cont.

- The method is fast enough to measure also the fast charge decay processes due to conductive fabric elements.
- A major hole of the method as a charge decay test is that it cannot distinguish between what happens in the volume of the material and at its surface - comparability of the results to tribocharging?
- The method is ***potentially suitable*** for all types of material ***but*** comparability to tribocharging is not yet shown.

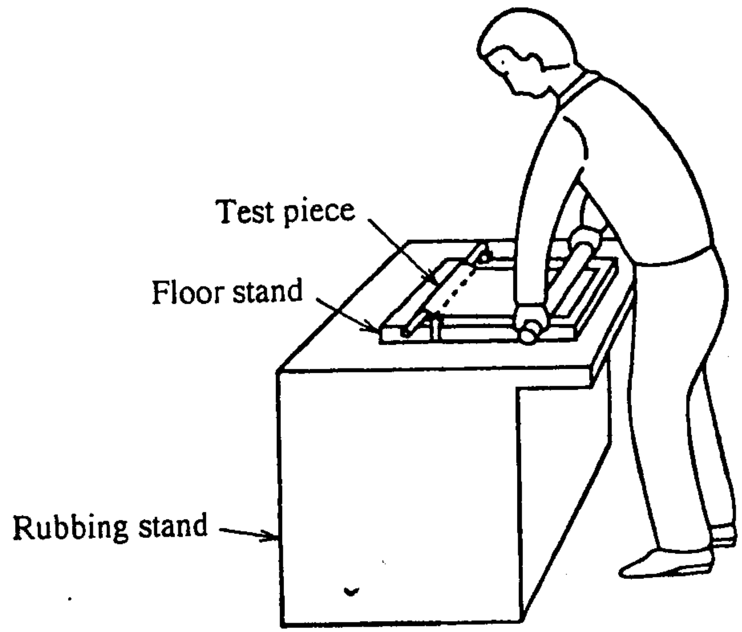
Evaluation of test methods for fabrics - measurement of chargeability (tribocharging test)

- Two potential methods considered:

prEN 1149-3, method 1 (tribocharging)



JIS L 1094:1997 "Frictionally charged electricity-amount measuring method



Measurement of chargeability

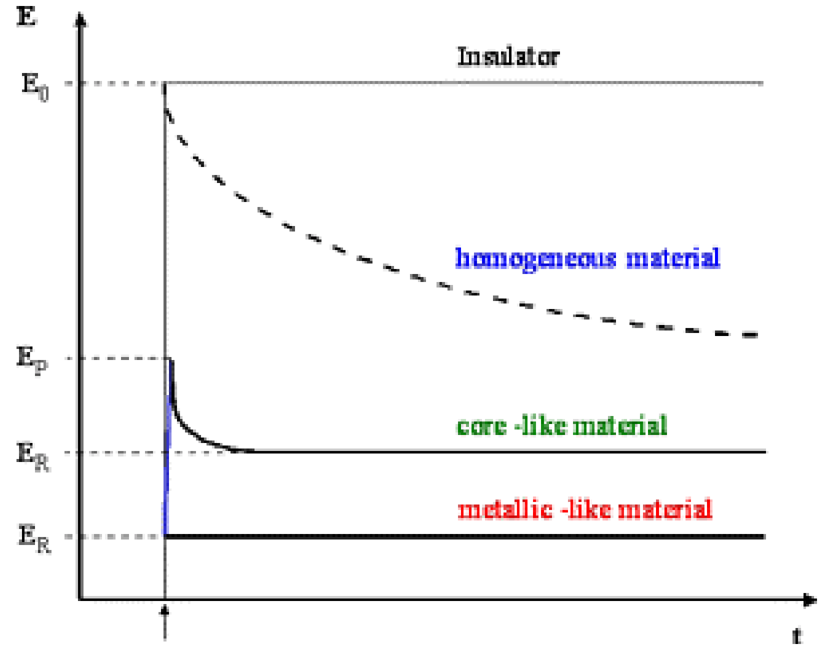
- The major weakness of both methods is the time delay between the fabric charging and the measurement:
  - In the prEN 1149-3 method the delay is ~0.1 s.
  - In the JIS L 1094 method the delay is a few seconds.
- In electronics applications the 0.1 s delay is acceptable but »1 s not.
- The reproducibility of the results was better with the prEN 1149-3 method.
- Another major weakness of the prEN 1149-3 is that the rubbing partners are at the middle (Al) and lower end (HDPE) of the triboelectric series. No partner at the upper end, such as PA.
- prEN 1149-3, method 1, is ***suitable*** for the characterisation of chargeability of all 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. electrostatic dissipative polyamide)

Evaluation of test methods for fabrics - measurement of electrostatic field shielding

prEN 1149-3 method 2 (induction charging)

- The method provides an efficient tool for studying the electrostatic shielding performance of garment fabric from electrostatic fields from underlaying garments.
- Electrostatic shielding performance of a fabric is described by a shielding factor

$$S = 1 - \frac{E_R}{E_0}$$



The method is ***suitable*** for the measurement of electrostatic shielding property of all fabrics

Evaluation of test methods for fabrics - measurement of "capacitance loading"

- Capacitance loading method is a new, not yet routine method by J. Chubb (IEC 101/146/NWIP, 2002, "Test method to determine the limitation of surface potential created by electrostatic charge retained on materials")
- It is based on the measurement of "capacitance loading" experienced by charge on the surface of material.
- It is a partner for the IEC 61340-2-1 corona charge decay test.
- Capacitance loading (CL) value is a ratio of the measured "capacitance" (Q/V) of the material under test to the "capacitance" (Q/V) of a very thin layer of good dielectric reference material.
- If CL is high, then only low surface voltages can be associated with practical quantities of charge (high voltage suppression).
- The method is ***potentially suitable*** for all kinds of fabrics, ***but*** correlation to garment level is still unclear, also questions about reproducibility.

Evaluation of existing test methods for garments

Evaluation of test methods for garments

Any good test method for ESD protective clothing should assess garment's ability to provide ESD protection.

Evaluation of test methods for garments

- The following existing test methods for full garments were selected for a comprehensive experimental evaluation
  - Resistive methods of IEC 61340-5-1 and ESD STM2.1
  - VTT's point-to-point charge decay method for garments
  - SP-Method 2175
  - STFI method PS07
  - Shirley method 202
  - JIS L 1094:1997, applied for full garments
- In this presentation the focus is in the most potential methods for a future IEC 61340 series garment standard

Evaluation of test methods for garments - Resistive methods of IEC 61340-5-1 and ESD STM2.1

- Point-to-point and sleeve-to-sleeve resistance; resistance to a groundable point.
- Basically the same assessment than at fabric level for the same reasons:
- Suitable for garments with homogeneous materials, but problems may arise when $R > 1 \times 10^{10}\ \Omega$.
- For heterogeneous, *surface conductive* garments ***suitable only*** in connection with other methods.
- ***Not suitable*** for garments with *core conductive* fibres.

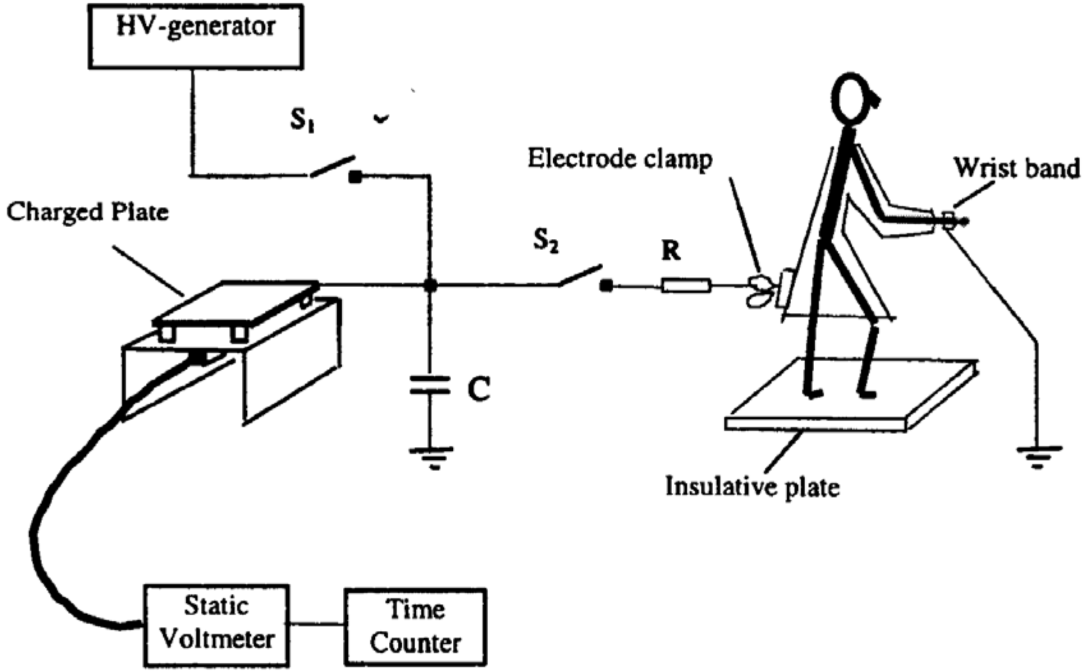
⇒Current standard resistance based standard test methods do not satisfactory characterise the protective performance of modern ESD garments. A garment may be rejected by inappropriate reasons.

Evaluation of test methods for garments - Resistive methods of IEC 61340-5-1 and ESD STM2.1 … cont.

- If modified to give a resistance to ground measurement also for those surface conductive garments which do not have a specific groundable point, the resistive methods have some value in verifying effective grounding of such materials that require it.
- Resistive measurements (point-to-point, resistance-to-ground, and perhaps vertical resistance EN 1149-2) are necessary when electrical safety is important.
- Resistive methods may still serve for periodic (auditing) testing for garments intended to be grounded in use. Such testing should focus on parameters potentially deteriorating in use.

Evaluation of test methods for garments - SP-Method 2175 Measurement of charge decay time of ESD-protective clothing

- The method is intended to verify that each panel of the garment has sufficient electrical connection to ground (under realistic, worst case operation conditions).



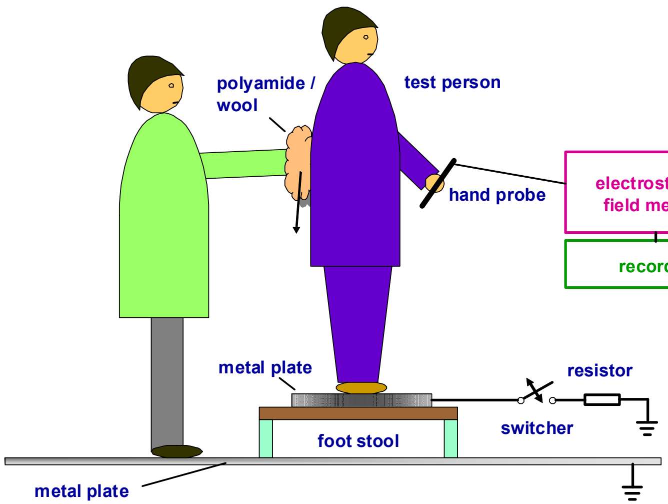
Evaluation of test methods for garments - SP-Method 2175 Measurement of charge decay time of ESD-protective clothing … cont.

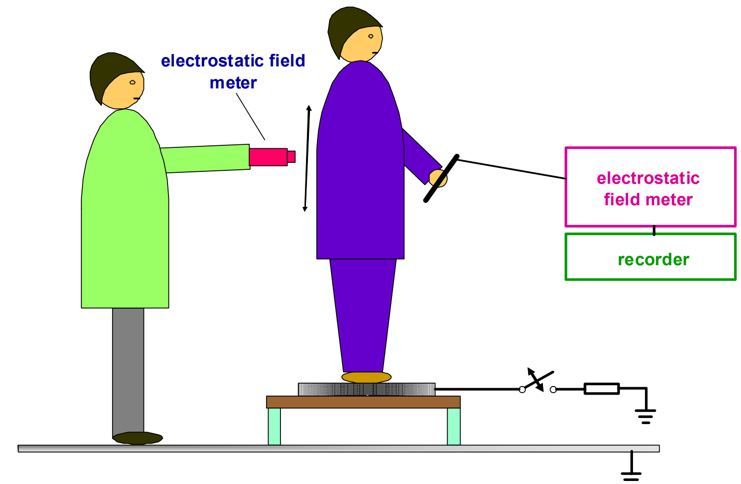
- The test focuses on the following key parameters:
  - Garment grounding
  - Charge decay of full garment
  - Voltage suppression of inhabited garment
- The method is ***suitable*** for garments with homogeneous or surface conductive heterogeneous materials (some modification preferable).
- The SP 2175 test is ***not suitable*** for garments intended to be ungrounded in use (core conductive garments).

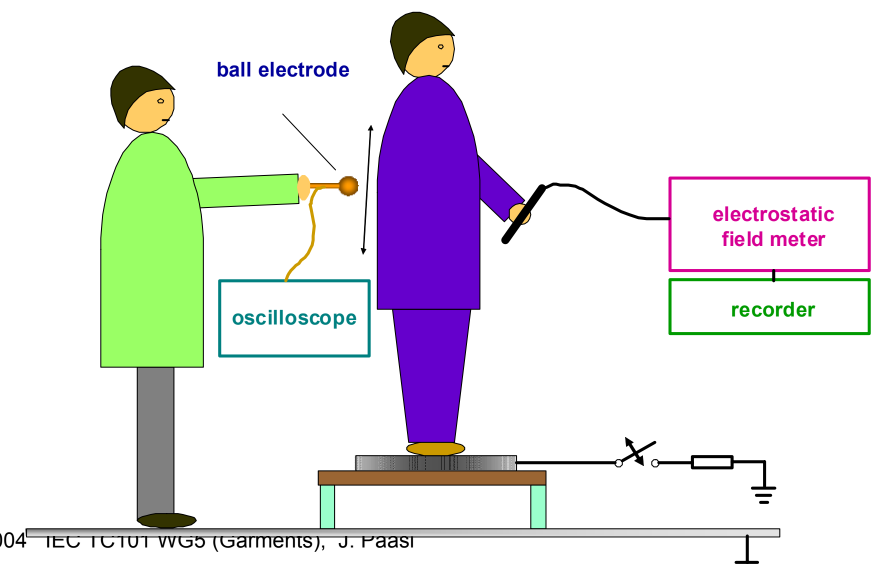
Evaluation of test methods for garments - STFI method No. PS07 “Charge transfer - garment test”

- The STFI method No. PS07 “Test method to determine the body potential and the charge transfer by wearing of electrostatic dissipative protective clothing” is a new laboratory method developed for the characterisation of protective clothing used in explosion dangerous areas.
- In the ESTAT-Garments project we have evaluated its general applicability to electronics manufacturing industry.

Evaluation of test methods for garments - STFI method No. PS07 “Charge transfer - garment test”







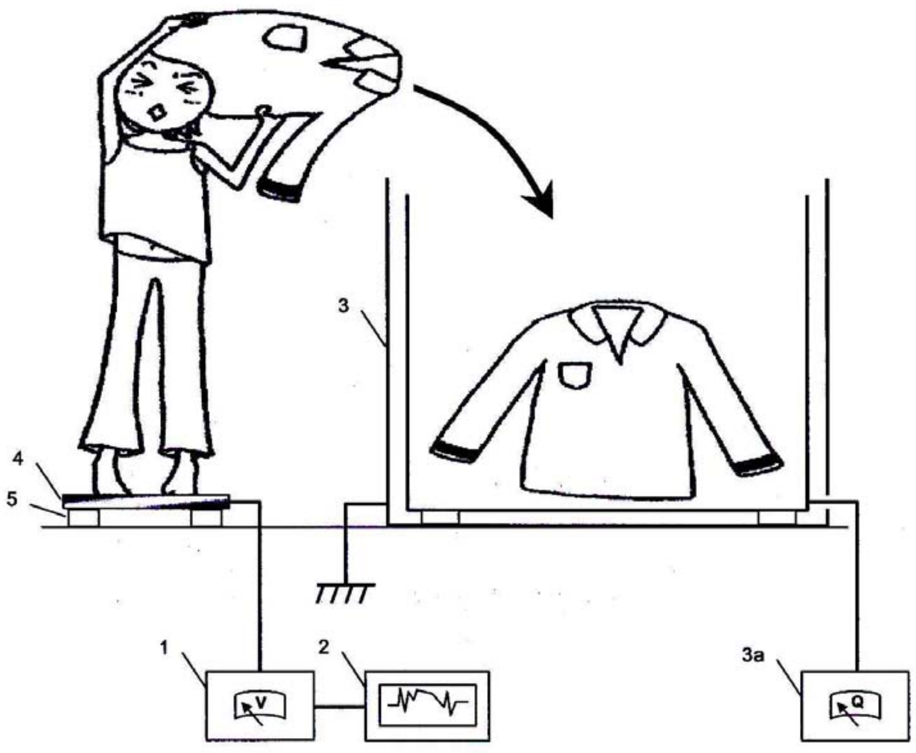
Evaluation of test methods for garments - STFI method No. PS07 “Charge transfer - garment test” …cont.

- The STFI PS07 method addresses two of the three key parameters (charge transfer, electric field external to the garment) identified to control in order to minimise ESD failures with reference to garments.
- The third one, peak ESD current, would be an easy enhancement of the method.
- The method is ***potentially suitable*** for all types of garments, ***but***
- The method has to be better specified in order to have better reproducibility of results (***modifications required***).

- The method would be particularly good for assessing garments used in flammable atmospheres.

Evaluation of test methods for garments - Shirley Method 202 “Static electricity when removing garment”

The method focuses on the chargeability of garment by triboelectrification



1 Electrostatic voltmeter
2 Recording device
3 Faraday pail with charge measuring device
4 Metal base plate
5 Insulating support

Evaluation of test methods for garments - Shirley Method 202 "Static electricity when removing garment"

- The method simulates the situation strictly forbidden in EPA.
- Questions also on the reproducibility of results.

⇒The method is ***unsuitable*** for ESD protective clothing.

- However, it is suitable for everyday clothing in casual environment

Modification of existing methods, new methods, etc.

Modification need for existing methods

- Resistive methods of IEC 61340-5-1
  - Modification to measure resistance-to-ground for all garments that require it (system measurement?)
  - Unsuitable for core conductive garments. Actions?
- IEC 61340-2-1 charge decay method (corona charging)
  - Currently unsuitable for state-of-the-art heterogeneous fabrics
  - Some modification and/or
  - Use only in connection with the “capacitance loading” measurement.
  - Capacitance loading method needs to be analysed in more detail
- prEN 1149-3, Method 1: Chargeability measurement
  - Need for a new rubbing partner, such as polyamide.

Modification need for existing methods

- SP Method 2175
  - Some modification needed in order to better take into account the voltage suppression effect of inhabited garments.
- STFI Method PS07
  - Better specification needed in order to increase the reproducibility of results to an acceptable level.
  - Ideal discharge probe for electronics industry applications?

Need for completely new methods

- Direct ESD test for fabrics
  - Measurement of direct ESD from charged fabrics (peak current and charge transfer).
- The presented methods, with the exception of resistive methods, would be suitable only to laboratory level approval tests to be done for new products or during product development phase.
- They may be too complex for periodic testing.

⇒Need for simple garment test for periodic and auditing testing

  - Resistance methods are unsuitable for core conductive garments and unreliable for surface conductive garments when $R > 1 \times 10^{10}\ \Omega$.
  - No need to cover all the critical parameters influencing the ESD protective performance because the periodic test is done for garments already passed an approval test.

Classification of garments

- Due to the very diverse requirements for ESD protective garments by different kinds of electronics manufacturers, there may be a need for different classes for ESD garments according to the protection they give.

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

Example of possible classification of ESD garments for a given relative humidity (12%RH, 23ºC)

Conclusions
and
Future steps

Conclusions

- Evaluation of existing methods for ESD garments and fabrics is completed.
- Current resistance based standard test methods do not satisfactory 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 fabric standards.
- Completely new simple methods would be also needed.
- Currently there are 5-6 potential methods for fabrics and 3-4 methods for full garments under consideration for approval tests + a couple of simple new methods for periodic tests under 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.

⇒Further work is required to select the minimum number of methods covering all important aspects.

Future steps in the ESTAT-Garments project

- Modification of the selected existing test methods is in progress.
- Development of new methods for simple periodic testing is in progress.
- Round robin tests will be carried out for selected new and modified existing methods by the end of 2004.
- Recommendations of test methods for a future IEC ESD garment and fabric standard(s) could be given in winter/spring 2005 after the round robin tests are completed, analysed and reported.
- Recommendations for the use of ESD garments will be given.
- Updating information is available at

http://estat.vtt.fi