Characterization of ESD shielding materials with novel test methods

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Abstract. Electrostatic discharge (ESD) shielding effectiveness of materials used to protect ESD sensitive devices was evaluated with a coaxial electrode and ESD generator. Attenuation of a continuous low power signal and a high power transient was measured. Electromagnetic far field shielding does not necessarily address ESD protection performance. High impedance on a discharge path reduces energy coupling efficiently. Therefore the prevention of conductive and capacitive coupling is the key factor for designing protective packaging for transportation of ESD sensitive devices. Due to the effect of breakdown field strength, low power signals shall not be used alone to assess ESD shielding characteristics. A coaxial electrode and an ESD generator was found a useful combination for the evaluation of ESD shielding effectiveness. As a final outcome, adequate ESD protection can be achieved even without the far field shielding, depending on application.

1. Introduction

Transportation of electrostatic discharge (ESD) sensitive devices outside an ESD protected area (EPA) requires packaging that provides electrostatic discharge shielding [1]. Different packaging structures can form adequate protection against ESD, but there are currently no supporting standard test methods available. The requirements and test methods are presented only for bags in terms of energy coupling. In accordance with the standard of International Electrotechnical Commission (IEC) 61340-4-8:2014 [2], ESD shielding bags are tested with a human body model discharge with a rise time of 5 ns to 20 ns and stress level of 50 µJ at 1 kV (100 pf/1500Ω). According to the previous studies [3,4], the slow rise time with the limited bandwidth and the low stress level are not realistic for ESD risk assessment.

The standard test method of ASTM D4935-18 [5] provides a procedure for measuring the electromagnetic (EM) shielding effectiveness (SE) of a planar material for a plane, far field EM wave. Electrostatic discharge is, however, a non-recurring phenomenon that may transfer energy non-linearly due to the voltage dependency and dielectric breakdown characteristics. In this study, ESD shielding effectiveness was characterized with a coaxial discharge electrode together with a system level ESD generator. Performance of the coaxial electrode was evaluated with a signal generator and a level meter and verified with simulations. Electrostatic discharge through the coaxial electrode was measured with a current transformer and oscilloscope. The shielding effectiveness of different packaging materials was then evaluated with different stress levels. Results are expressed as energy attenuation.
2. Experimental

All the measurements were made in laboratory conditions of (12 ± 3) %rh and (23 ± 2) °C with two opposite coaxial electrodes. A diameter of outer electrodes was 70 mm. Wall thickness was 10 mm and a length of the electrodes was 50 mm. Inner electrodes were replaceable. The electrodes with diameters of 30 mm and 20 mm are shown in figure 1. Inner electrodes were mounted with PVC bars and 4 mm screws. The thickness of the inner electrodes was 10 mm. A complete electrode system is shown in figure 2. This is also a 3D simulation setup used for the system verification.

![Bottom and top electrodes](image1)

![Electrode system](image2)

**Figure 1.** Bottom and top electrodes  
**Figure 2.** Electrode system

Performance of the electrode system was assessed without the specimen. A signal generator was connected to the top electrode via 50 Ω coaxial cable. A level meter was connected to the bottom electrode through the 50 Ω power sensor. A sine wave in a frequency range of 5 MHz to 1 GHz was then applied to the electrode system. Signal level was 0 dBm (223.6 mV at 50 Ω). An example of the shorted electrode verification is shown in figure 3. Connections and the specimen cause an impedance mismatch. The system shall be verified with the different thicknesses of the packaging.

After electrode verification, measurements were repeated with ten different types of shielding bags and five other types of planar samples. A diameter of the specimen was 70 mm. Shielding effectiveness is expressed as

\[
SE = 10\log \frac{P_1}{P_2} (\text{dB}) = 20\log \frac{V_1}{V_2} (\text{dB}),
\]

where \(P_1\) is the power and \(V_1\) is the voltage with the specimen. \(P_2\) and \(V_2\) are the reference values without the specimen.

ESD shielding effectiveness (\(SE_{ESD}\)) of the sample was then characterized by replacing the signal generator with a system level ESD generator of IEC 61000-4-2:2008 [6] and by replacing the level meter with a shorting wire and current transformer of Tektronix CT1. A transformer was completely shielded with a copper film. Measurements were made with a digital storage oscilloscope of 4 GHz and 20 GS/s. ESD energy was integrated over 330 Ω resistor of the ESD generator from the current waveform with equation 2. ESD Shielding effectiveness is calculated according to equation 3.

\[
W = \int_{t_0}^{t} i^2 R \, dt = \frac{C \times V^2}{2}
\]

\[
SE_{ESD} = 10\log \frac{W_1}{W_2} (\text{dB}),
\]

where \(W_1\) is the energy with the specimen and \(W_2\) is the energy without the specimen.

The electrode performance and shielding effectiveness of PET film was verified with finite element method (FEM) simulations. ESD energy attenuation was modelled with a combination of SPICE and FEM simulation, where IEC pulse was applied on the top of the outer electrode in figure 2. SPICE circuit has an equivalent circuit model for the IEC source and for the physical current measurement setup.
3. Results
Figure 3 shows the performance of the electrode system with the Ø 30 mm inner electrode. Examples of \( SE \) with different materials are shown in figure 4. Figure 5 shows \( SE \) of ten different types of shielding bags with Ø 30 mm electrode. The effect of the electrode size was evaluated with 200 \( \mu \)m PET film and electrodes of Ø 30 mm, Ø 20 mm and Ø 10 mm (figure 6).

![Figure 3](image3.png)

**Figure 3.** Electrode performance.

![Figure 4](image4.png)

**Figure 4.** \( SE \) of different materials.

![Figure 5](image5.png)

**Figure 5.** \( SE \) of ESD shielding bags.

![Figure 6](image6.png)

**Figure 6.** \( SE \) of PET with three electrodes.

ESD energy measurement and simulation at 75 \( \mu \)J is shown in figure 7. Figure 8 shows results of 200 \( \mu \)m PET film (\( SE_{ESD} = -7 \) dB). \( SE_{ESD} \) of ten different shielding bags (arithmetic means of ten measurements) with different stress levels are shown in figure 9. Figure 10 shows results of the following materials: LDPE bag with carbon grids \( (d = 40 \mu \)m), Antistatic LDPE bag \( (d = 80 \mu \)m), Clamshell (PVC, \( d = 800 \mu \)m), Clamshell (PVC, \( d = 800 \mu \)m) and air gap \( (d = 800 \mu \)m), and E flute cardboard \( (d = 1.2 \) mm).

![Figure 7](image7.png)

**Figure 7.** Reference current and energy.

![Figure 8](image8.png)

**Figure 8.** \( SE_{ESD} \) measurement of PET film.
4. Discussion
A cut of frequency of the electrode system was approximately 500 MHz (3 dB). An insulating sample blocks low frequencies due to the high impedance of the capacitive electrode system. Occasionally, breakdowns occurred with the shielding bags at 8 kV stress level. ESD peak currents varied due to the complex source and drain impedances and non-linear behavior of multilayer samples. A clam shell with 800 µm air gap provided better ESD shielding than the shielding bags at 8 kV stress level. Breakdowns were not observed with clamshells. E-flute cardboard lost shielding efficiency at 8 kV.

Shielding effectiveness of the plane far field EM wave was measured with a constant power of 1 mW. Peak power of ESD transient at 8 kV was 190 kW. From this perspective, the shielding against radiated low power signals can generally be ignored. The difference between an open and closed packaging is insignificant compared to the direct energy coupling. Demonstration of shielding effectiveness with EMI locators is considered inadequate for ESD control packaging.

5. Conclusions
ESD shielding effectiveness depends highly on the stress levels. A thick PET of clamshell packaging with an air gap provided adequate shielding against direct ESD.

A plane far field EM wave shall not be used alone in characterization of ESD protection capability. Radiated EMI risk may be overestimated with the packaging of unpowered and electrically floating devices.

The method described had many advantages compared to the standard test method of ESD shielding bags. ESD shielding shall be characterized with the realistic stress levels and adequate bandwidth. Further studies shall cover higher frequencies, peak currents and statistical uncertainty of the breakdown.

References
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