

1. Standard Requirements for Electrostatic Discharge Generator

Testing of electrostatic discharge (ESD) is standardized by the International Electrotechnical Commission (IEC) under IEC 61000-4-2:2008 [1] and by the European Committee for Electrotechnical Standardization (CENELEC) under EN 61000-4-2:2009 [2]. These two standards are practically the same. The latest versions are from 2008 and 2009, respectively. There are other standards related to ESD, but they are out of the scope of this work [3].

The standard IEC 61000-4-2:2008 deals with the immunity requirements and test methods for electrical and electronic equipment subjected to static electricity discharges between humans and equipment. The goal of IEC 61000-4-2 is to establish replicable evaluation of ESD immunity testing. Therefore, IEC 61000-4-2 is the cornerstone for ESD testing [1]–[7].

The standard IEC 61000-4-2 defines two methods for ESD testing:

- (1) the contact discharge, in which case the electrode of the ESD testing generator is kept in (electrical) contact with the equipment under test (EUT) or surrounding conductive objects, while the discharge is initiated using a switch in the generator and
- (2) the air discharge, in which case the charged electrode of the ESD generator is moved towards the EUT until the spark is formed in the air or the generator electrode touches EUT.

Contact discharge is the default and primary testing method. Air discharge is used only in cases when the contact discharge can not be performed.

There are standardized test levels in IEC 61000-4-2 given in Table I.

Table I. Standard ESD test levels.

Discharge voltage	Testing level				
	1	2	3	4	Dedicated equipment
Contact discharge voltage [kV]	2	4	6	8	Additional specification
Air discharge voltage [kV]	2	4	8	15	Additional specification

A simplified electrical scheme of the ESD generator is shown in Fig. 1. The high-voltage direct current (DC) generator E charges the capacitor C through resistor R_1 when the switch Π_1 is closed, while the discharge switch Π_2 is open. Once the capacitor C reaches voltage E the switch Π_1 can be opened. The discharge is then initiated by closing the switch Π_2 .

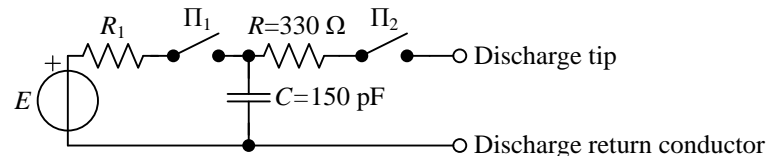


Figure 1. Simplified electrical scheme of the ESD generator.

Requirements for the ESD generator are:

- (1) the equivalent capacitance seen from the output terminals $C = 150 \text{ pF}$,
- (2) the equivalent resistance seen from the output terminals $R = 330 \Omega$,
- (3) the open-circuit output voltage at terminals from 1 kV to 8 kV for the contact discharge,
- (4) the open-circuit output voltage at terminals from 2 kV to 15 kV for the air discharge,
- (5) the tolerance of the open-circuit output voltage is $\pm 5\%$,
- (6) both positive and negative polarity of the output voltages for all levels,
- (7) regular mode of operation is a single discharge; however pulse repetition rate of 20 discharges per second is needed for exploration of EUT weaknesses to ESD immunity and
- (8) once charged, the ESD generator should be able to hold the open-circuit output voltage for at least 5 s.

The discharge (pulse) current that occurs during contact discharge is used to evaluate the ESD generator and this current has the following requirements:

- (1) the waveform of the discharge (pulse) current as it is shown in Fig. 2 and
- (2) parameters of the discharge (pulse) current as given in Table II.

Note that the ESD current waveform has three significant points: the maximal (peak) value, I_{\max} , the value at 30 ns, I_{30} and the value at 60 ns, I_{60} .

ESD generator should minimize unintended electromagnetic radiation and conducted emission.

Electrodes of the ESD generator have standardized and different shapes for the contact discharge (shown in Fig. 3) and for the air discharge (shown in Fig. 4). The tip of the discharge electrode should be interchangeable.

The length of the return conductor (cable, strap) of the ESD generator should be (2 ± 0.05) m .

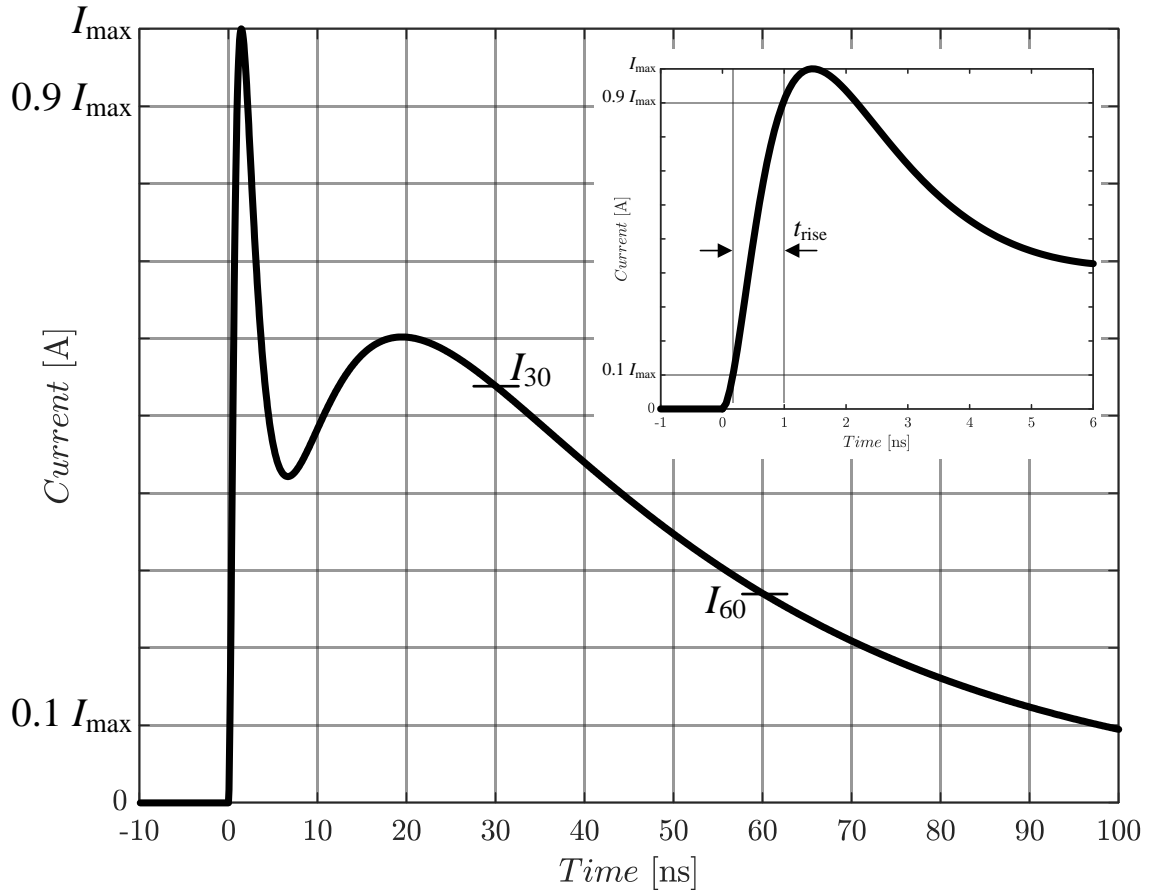


Figure 2. Standard waveform of ESD current for contact discharge. The leading edge is shown in the inset.

Table II. Parameters of ESD current.

The parameter of the ESD generator	Testing level			
	1	2	3	4
Voltage [kV]	2	4	6	8
I_{max} ($\pm 15\%$) [A]	7.5	15.0	22.5	30.0
Rise time ($\pm 25\%$), i.e., time between $0.1 I_{max}$ and $0.9 I_{max}$ for 1 st peak [ns]	0.8	0.8	0.8	0.8
I_{30} ($\pm 30\%$) [A]	4	8	12	16
I_{60} ($\pm 30\%$) [A]	2	4	6	8

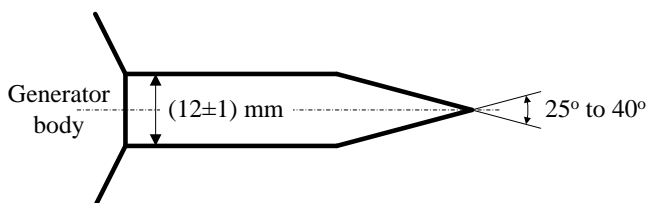


Figure 3. Sharp electrode for contact discharge.

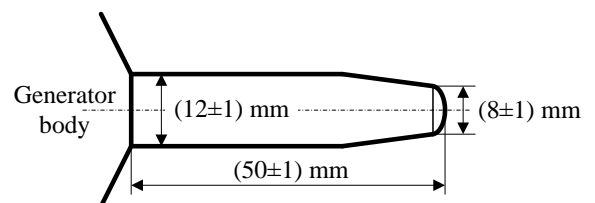


Figure 4. Rounded electrode for air discharge.

The standard also defines test setup in details and the verification procedure for the ESD generator.

References

- [1] <https://webstore.iec.ch/publication/4189> (accessed 1. June 2024.)
- [2] <https://standards.globalspec.com/std/1174504/en-61000-4-2> (accessed 1. June 2024.)
- [3] ISO 10605:2023, <https://www.iso.org/standard/79094.html> (accessed 5. June 2024.)
- [4] T. Williams *EMC for Product Designers*, 3rd edition, Newnes, Oxford, UK, 2001.
- [5] C. Paul *Introduction to Electromagnetic Compatibility*, 2nd edition, Wiley, 2006.
- [6] White Paper 3 System Level ESD Part I: Common Misconceptions and Recommended Basic Approach, Industry Council on ESD Target Levels, 2010. [link](#) (accessed 5. June 2024.)
- [7] White Paper 3 System Level ESD Part II: Implementation of Effective ESD Robust Designs Industry Council on ESD Target Levels, Industry Council on ESD Target Levels, 2012. [link](#) (accessed 5. June 2024.)

2. Overview of Specifications for Commercial ESD Generators

In order to get an insight into specifications of commercially available ESD generators, we have assembled a list of all generators for which we could find data online. The data is taken from the publicly available specifications by the manufacturers.

Generally, there are two types of ESD generators: (1) with the open-circuit output voltage up to approximately 16 kV given in Table III and (2) with the open-circuit output voltage up to approximately 30 kV given in Table IV. In Tables III and IV, below the model name, there is a link from which the data is taken. The last line in Tables III and IV contains the best found specifications among all ESD generators within the table.

3. Tentative Specifications for Open-Hardware ESD Generator

Based on the requirements from the IEC 61000-4-2 standard and the specifications for the commercially available ESD generators given in Tables III and IV, we summarize (tentative) standard and additional technical specifications of our open-hardware ESD generator.

The standard technical specifications for the open-hardware ESD generator are those from IEC 61000-4-2:

- (1) the equivalent capacitance seen from the output terminals approximately $C = 150 \text{ pF}$,
- (2) the equivalent resistance seen from the output terminals approximately $R = 330 \Omega$,
- (3) the open-circuit output voltage at terminals from 1 kV (or lower) to 8 kV for the contact discharge,
- (4) the open-circuit output voltage at terminals from 2 kV (or lower) to 15 kV for the air discharge,
- (5) the tolerance of the open-circuit output voltage $\pm 5 \%$,
- (6) both positive and negative polarity of the output voltages for all levels,
- (7) a single discharge mode,
- (8) once charged, the ESD generator should be able to hold open-circuit output voltage for at least 5 s,
- (9) the discharge (pulse) current deviates standard waveform (Fig. 2) within maximum limits (Table II) when the influence of the ESD generator strap is negligible.

Additional technical specifications for the open-hardware ESD generator are the best ones from Tables III and IV:

- (1) the open-circuit output voltage at terminals from 1 kV (or lower) to 30 kV for both contact and air discharge,
- (2) fine step of 100 V for output voltage,
- (3) continuous discharge mode,
- (4) automatic pulse counter,
- (5) repetitive discharge mode with up to 20 Hz frequency,
- (6) automatic switching of polarity,
- (7) LCD with information about ESD generator state and
- (8) battery-powered.

Table III. Overview of specifications for 16 kV ESD generators.

No.	Model	Discharge voltage		Polarity	Operating modes	Rise time [ns]	Current deviations			Holding time
		Air	Contact				First peak	After 30 ns	After 60 ns	
1.	Teseq NSG 435 link	0.2–16.5 kV (100 V steps) ±5%	0.2–9 kV (100 V steps) ±5%	Positive, negative, automatic change	Single: pulse counter: 0–9999; Repetition: (air) 0.5/1/5/10/20/25 Hz; (contact) 0.5/1/5/ 10 Hz; Continuous;	0.7–1	±10%	±30%	±30%	>5 s
2.	Haefely ONYX 16 link	1–16 kV (100 V steps)	1–16 kV (100 V steps)	Positive, negative	Single: pulse counter: 1–9999; Repetition: 0.1/0.2/0.5/1/2/5/10/20 Hz; Continuous;	0.8±25%	±15%	±30%	±30%	>5 s
3.	Haefely PESD 1610 link	0.2–16.5 kV (100 V steps)	0.2–9 kV (100 V steps)	Positive, negative	Single: pulse counter: 0–9999; Repetition: 1/2/5/10/20 Hz; Continuous;	N/A	N/A	N/A	N/A	N/A
4.	EM Test Dito link	0.5–16.5 kV (100 V steps) ±5%	0.5–10 kV (100 V steps) ±5%	Positive, negative	Single; Repetition: (air) up to 20 Hz; (contact) up to 10 Hz;	0.8±25%	±15%	±30%	±30%	>5 s
5.	Keytek Minizap MZ-15/EC link	±0.5–15 kV	±0.5–8 kV (10 V steps) ±5%	N/A	Single; Repetition: 1 Hz and 20 Hz;	0.7–1	N/A	N/A	N/A	N/A
6.	The EMC Shop ESD16 SIMULATOR 16.5 KV link	0.2–16.5 kV (100 V steps)	0.2–10 kV (100 V steps)	Positive, negative, alternate	Single: pulse counter: 0–9999; Repetition: (air) frequency depends on the distance between the discharge electrodes and the examinant; (contact) 0.1/0.2/1/2/5/10/20 Hz; Continuous;	0.8±25%	±15%	±30%	±30%	≥5 s
7.	3ctest EDS 16H link	1–16 kV (100 V steps) ±5%	1–16 kV (100 V steps) ±5%	Positive, negative	Single: pulse counter: 0–9999; Repetition: 0.1/0.2/0.5/1/2/5/10/20 Hz;	0.8±25%	N/A	N/A	N/A	>5 s
8.	3ctest EDS 20H link	1–18 kV (100 V steps) ±5%	1–18 kV (100 V steps) ±5%	Positive, negative, automatic switching	Single: pulse counter: 0–9999, Repetition: 0.1/0.2/0.5/1/2/5/10/20 Hz;	0.8±25%	±15%	±30%	±30%	>5 s

No.	Model	Discharge voltage		Polarity	Operating modes	Rise time [ns]	Current deviations			Holding time
		Air	Contact				First peak	After 30 ns	After 60 ns	
9.	ESD3000 GENERATOR (ESD3000DM1) link	0.2–16 kV (100 V steps) ±5%	0.2–10 kV (100 V steps) ±5%	Positive, negative, alternate	Single: pulse counter: 1–29999; Repetition: (air) ≥ 30 Hz or more; (contact) max. 20 Hz (pulse every 0.05, 0.1, 0.2 ... 60 s);	0.8±25%	±15%	±30%	±30%	≥5 s
10.	EMCSOSIN ESD 20k link	0.2–20 kV		Positive, negative, alternate	Single: pulse counter: 1–9999; Repetition.: 0.1–20 Hz; Continuous;	0.6–1	N/A	N/A	N/A	≥5 s
11.	Schloder SESD 216 link	0.2–16.5 kV (100 V steps)	0.2–10 kV (100 V steps)	Positive, negative	Single: pulse counter: 1–9999; Repetition: (air) frequency depends on the distance between the discharge electrodes and the examinant; (contact) 0.1/0.2/1/2/5/10/20 Hz; Continuous;	0.8±25%	±15%	±30%	±30%	≥5 s
THE BEST		0.2–16 kV (16.5 kV, 18 kV, 20 kV) (100 V steps) ±5%		Positive, negative, alternate, automatic change	Single: pulse counter: 1–29999; Repetition: (air) 0.1/0.2/0.5/1/5/10/20/25 Hz; (contact) 0.1/0.2/0.5/1/5/10/20 Hz; Continuous;	0.6–1	±10%	±30%	±30%	>5 s

Table IV. Overview of specifications for 30 kV ESD generators.

No.	Model	Discharge voltage		Polarity	Operating modes	Rise time [ns]	Current deviations			Holding time
		Air	Contact				First peak	After 30 ns	After 60 ns	
1.	Teseq NSG 437	0.2–30 kV (100 V steps) ±5%	0.2–30 kV (100 V steps) ±5%	Positive, negative, automatic change	Single: pulse counter: 1–9999; Repetition: (air) 0.5/1/5/10/20/25 Hz; (contact) 0.5/1/5/10/20 Hz; Continuous;	N/A	N/A	N/A	N/A	>5 s
2.	Teseq NSG 438/NSG 438A	0.2–30 kV (100 V steps) ±5%	0.2–30 kV (100 V steps) ±5%	Positive, negative, automatic change	Single: pulse counter: 1–9999; Repetition: (air) 0.5/1/5/10/20/25 Hz; (contact) 0.5/1/5/10/20 Hz; Continuous;	N/A	N/A	N/A	N/A	>5 s
3.	Haefely PESD 3010	1–30 kV (100 V steps)	1–30 kV (100 V steps)	Positive, negative	Single: pulse counter: 0–9999; Repetition: 0.1/0.2/1/2/5/10/20 Hz; Continuous;	N/A	N/A	N/A	N/A	N/A
4.	Haefely ONYX 30	1–30 kV (100 V steps) ±5%	1–30 kV (100 V steps) ±5%	Positive, negative	Single: pulse counter: 0–9999; Repetition: 0.1/0.2/0.5/1/2/5/10/20 Hz; Continuous;	0.8±25%	±15%	±30%	±30%	>5 s
5.	ESD NX30	0.2–30 kV (100 V steps) ±5%	0.2–30 kV (100 V steps) ±5%	Positive, negative	Single: pulse counter: 0–9999; Repetition: (air) up to 25 Hz; (contact) up to 20 Hz; Continuous: (air);	0.8±25%	±15% (Level 1–4)	±30% (Level 1–4)	±30% (Level 1–4)	≥5s
6.	Schloder SESD 230	0.5–30 kV (100 V steps)	0.5–30 kV (100 V steps)	Positive, negative	Single: pulse counter: 0–9999; Repetition: (air) frequency depends on the distance between the discharge electrodes and the examinant; (contact) 0.1/0.2/1/2/5/10/20 Hz; Continuous;	0.8±25%	±15%	±30%	±30%	≥5s
7.	Schloder SESD 30000	1–30 kV (100 V steps)	1–30 kV (100 V steps)	Positive, negative	Single: pulse counter: 1–9999; Repetition: (air) multiple pulses; (contact) 0.1/0.2/1/2/5/10/20 Hz; Continuous;	N/A	N/A	N/A	N/A	≥5s

No.	Model	Discharge voltage		Polarity	Operating modes	Rise time [ns]	Current deviations			Holding time
		Air	Contact				First peak	After 30 ns	After 60 ns	
8.	Noiseken ESS-S3011A & GT-30RA link	0.2–30 kV (100 V steps) 0.2–2 kV: ±10% 2–30 kV: ±5%		Positive, negative	Single: pulse counter: 1–60000; Repetition: 0.002–20 Hz; Continuous;	0.7–1	±10%	±30%	±30%	≥5s
9.	Noiseken ESS-B3011A & GT-30RA link	0.2–30 kV (100 V steps) 0.2–2 kV: ±10% 2–30 kV: ±5%		Positive, negative	Single: pulse counter: 1–999; Repetition: 0.1–20 Hz; Continuous;	0.7–1	±10%	±30%	±30%	≥5s
10.	EDS 30T link	0.2–30 kV (100 V steps) ±5%	0.2–30 kV (100 V steps) ±5%	Positive, negative	Single: pulse counter: 1–9999; Repetition: 0.1/0.2/0.5/1/2/5/10/20 Hz;	0.8±25%	N/A	N/A	N/A	>5 s
11.	ESD3000 GENERATOR RM32 required (ESD3000DN1) link	1–30 kV (100 V steps)	1–30 kV (100 V steps)	Positive, negative, alternate	Single: pulse counter: 1–29999; Repetition: (air) ≥ 30 Hz or more; (contact) max. 20 Hz (pulse every 0.05, 0.1, 0.2 ... 60 s);	0.8±25%	N/A	N/A	N/A	≥5s
12.	EMCSOSIN ESD 30k link	0.2–30 kV		Positive, negative, alternate	Single: pulse counter: 1–9999; Repetition.: 0.1–20 Hz; Continuous;	0.6–1	N/A	N/A	N/A	≥5s
13.	Kikusui KES4022A link	0.5–30 kV		Positive, negative	Single: pulse counter: 0–99999; Repetition: 0.01–10 Hz; Continuous;	0.8±25%	N/A	N/A	N/A	≥5s
THE BEST		0.2–30 kV (100 V steps) ±5%		Positive, negative, alternate, automatic change	Single: pulse counter: 1–99999; Repetition: (air) 0.01–25 Hz; (contact) 0.01–20 Hz; Continuous;	0.6–1	±10%	±30%	±30%	>5 s

Revision history

Version	Date	Author(s)	Description
1.0	07/06/2024	D.O., J.D.	Initial release.