

## Modeling and Practical Suggestions to Improve ESD Immunity Test Repeatability

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**Abstract**-Electrostatic discharge (ESD) immunity tests are widely carried out in order to assess the immunity level of several electrical and electronic equipment. ESD is a severe source of interference which can produce damages, upset or failures in any electronic system. One important outcome of the ESD tests is the evaluation of the test uncertainty, mainly the uncertainty contribution associated to the repeatability, that is usually very low. The main problems affecting the uncertainty evaluation are underlined. The aim of the paper is to suggest improvements in the measurement set-up, by means of both practical and modelling solutions.

### I. Introduction

The European Directive 89/336/EEC on electromagnetic compatibility (EMC) prescribes to perform a lot of tests on electrical and electronic equipment in order to guarantee both low electromagnetic emission levels and a sufficient immunity degree against different kinds of disturbance present in the environment. One of the most severe immunity test concerns the ESDs, which can momentarily disturb the operation of a system or provoke failures and even permanent damages. ESD on electronic devices can occur when a device becomes charged by triboelectrification and approaches another conductor or while a human charged by triboelectrification handles the device. Charge accumulation by triboelectrification or induction process are at the origin of any ESD event. The effects produced by ESD are usually observed by separating conducted interference (i.e. direct effect) due to the direct injection of the discharge current in the victim device, and radiated interference (i.e. indirect effect) related to the coupling with the electromagnetic field radiated by the ESD event.

During the last years, a great effort has been addressed by the scientific community to establish ESD standard procedures. To this aim, an important role has been played by several studies on ESD current waveform, focusing the attention on the amplitude and rise-time variations due to different voltages, approach speeds, relative humidity and electrode shapes [1],[2].

The immunity test has to comply with the standard IEC 61000-4-2 [3], where immunity requirements and test methods are fixed for equipment which must withstand ESD, either directly or indirectly. The standard considers two test methods: the contact discharge (CD) and the air discharge (AD) methods. The characteristics of the ESDs are provided and are used in the setup stage of the ESD generator in order to provide discharges similar to those generated by the human body.

To guarantee the reproducibility of the results, the traceability of ESD generators, obtained by periodical calibrations, has to be performed. The many years' experience of INRiM in calibration activity and international comparisons [4] demonstrate that considerable differences may occur in the test results especially when generators of different manufacturers are used. This fact has important effects with regard to the decisions to be taken as to the compliance with the requirements of the EMC Directive.

### II. Measurement set-up

The measurement set-up employed in the calibration of ESD generators is, in general, made by several blocks (Fig. 1): the ESD generator (also known as "gun") can be modelled by means of a basic equivalent circuit [3], consisting of an high voltage DC supply, a charging resistor  $R_c$ , an energy-storage capacitor  $C_s$ , a discharging resistor  $R_d$ , a discharge switch  $S$  and a discharge return connection.

In the CD method, the generator discharge tip is kept in direct contact with the equipment under test (EUT) and the discharge is fired by turning on the switch  $S$ . In the AD method, being  $S$  closed, the discharge tip is approached to the EUT until an air discharge is obtained.

The simulator is often equipped with a discharge network plug-in, which allows different choices for  $C_s$  and  $R_d$ .

whose values range from 100 pF to 330 pF and from 330  $\Omega$  to 2000  $\Omega$ . The immunity level is defined as the charge voltage of the capacitor  $C_s$ . The levels fixed by the EMC standards [3], [5] extend from 2 kV to 25 kV. The discharge current return connection between the generator and the reference ground is usually made of a ground strap cable. The current transducer (often called “target”) has to be realized with a low impedance of 2  $\Omega$  on the test side. The target is mounted in the centre of a vertical metal plane. An attenuator and a RF coaxial cable is used to improve the impedance matching and to carry the signal to the measurement instrument. The measurement instrumentation, i.e. a digital oscilloscope is employed to analyse the discharge current waveform in the time domain. It is placed inside a Faraday cage to prevent it from the electromagnetic field radiated by the ESD.

As already mentioned, the ESD events are highly non-repeatable. The calibration of the ESD generator represents an important contribution to the uncertainty budget. In order to provide some uncertainty percentage values, reference [2] specifies the following typical contributions derived from many reports by accredited calibration laboratories: 8% for the current peak value and 5-7% for the rise time in the CD mode, 25% for the rise time and 10-15% for the discharge time constant in the AD mode. The type A contribution cannot be better than 20% for ten to twenty repeated ADs, whereas it is usually in the order of 3% to 5% for ten repeated CDs.

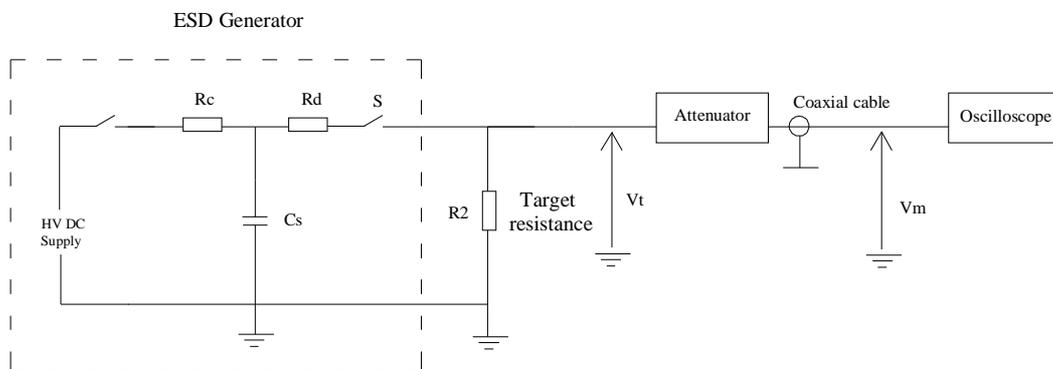


Figure 1. Measurement system for the ESD generator calibration.

### III. Problems in calibration of ESD simulators

The two above-mentioned test methods imply two different calibration methods. First of all, the IEC standard [3] identifies the CD method as the preferred test method, whereas air discharges shall be used where contact discharges cannot be applied. As far as the contact discharge method is concerned, the EMC standards recommend to check some waveform parameters related to the discharge current : the main parameters to be verified are the first peak value, the rise-time, and the current values at 30 ns and 60 ns. The calibration of an ESD generator consists in measuring those parameter values and complying with the tolerances indicated in Table I.

Table I. Contact discharge current waveform parameters and tolerances (IEC 61000-4-2).

Level	Indicated voltage kV	First peak current of discharge ( $\pm 15\%$ ) A	Rise time $t_r$ ( $\pm 25\%$ ) ns	Current ( $\pm 30\%$ ) at 30 ns A	Current ( $\pm 30\%$ ) at 60 ns A
1	2	7.5	0.8	4	2
2	4	15	0.8	8	4
3	6	22.5	0.8	12	6
4	8	30	0.8	16	8

The current has to be detected by means of the small-inductance coaxial shunt (the “target”), together with an oscilloscope with a minimum bandwidth of 2 GHz. Annex B of the IEC standard [3] specifies the requirements to build a target, together with the details of the transfer impedance of the target-attenuator-cable chain.

As far as the AD method is concerned, EMC standards do not recommend any specific calibration method. Only the tolerance of the charge voltage value is specified.

#### IV. Developments and improvements

INRiM has developed a system to calibrate ESD generators. A coaxial shunt, used in the CD calibration test, has been accurately characterised and its frequency response has been evaluated by means of a vector network analyzer up to 4 GHz (Table II and III). Table II shows the good agreement between the measured DC resistance and the requirement of the Annex C of [3]. The insertion loss values, reported in Table III, are well within  $\pm 0.5$  dB over the whole frequency range from 10 kHz to 4 GHz, fulfilling again the IEC standard prescriptions.

Table II. Target input DC resistance.

Nominal value:	2.000 $\Omega$
Measured value:	1.971 $\Omega$
Uncertainty:	0.006 $\Omega$

Table III. Insertion Loss as a function of frequency.

Frequency (MHz)	Insertion Loss (dB)	Uncertainty (dB)
0.01	42.67	0.40
1	42.78	0.29
100	42.93	0.28
1000	43.08	0.28
2000	43.19	0.28
4000	42.35	0.33

With regard to the calibration set-up, a great effort is addressed on the implementation of a suitable non-commercial numerical model, which allows to compute and identify optimal set-up configurations, in order to improve the measurement repeatability and reproducibility.

In the literature, some authors have proposed both circuitual and full-wave ESD generator models [2],[6],[7]. To assure model accuracy, a key issue is the accurate computation of those stray distributed parameters which strongly affect the discharge current waveform, in particular the current tail.

A preliminary analysis of some stray parameter effects on the ESD waveform can be carried out through the circuitual model [2], sketched in Fig. 2, where the indicated parameter values are considered as “basic” values:

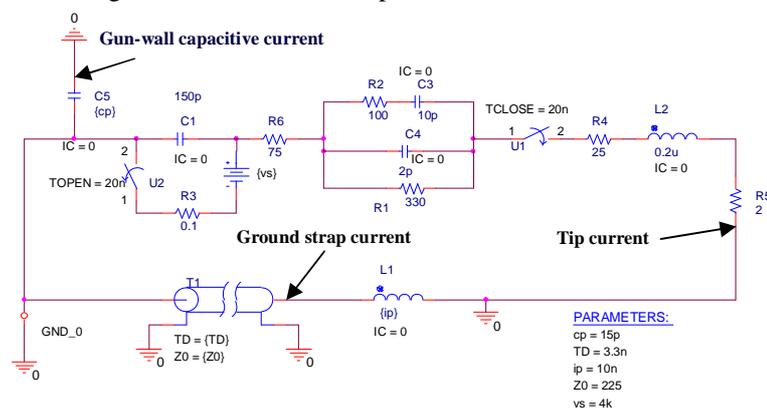


Figure 2. Circuit model of the ESD generator and the experimental set-up.

As a first step, it is interesting to look at the waveforms of the tip, the gun-wall capacitive and the ground-strap currents (Fig. 3). It should be noted the great influence of the stray capacitance  $C_5$  between the gun and the metallic wall at the beginning of the discharge. In fact, during the first instants, most of the discharge current returns flowing through the stray capacitance rather than the ground-strap cable.

In order to investigate the sensitivity of the tip current waveform to the stray parameters, it is interesting to analyse different circuitual configurations, in which one or more parameters are changed within an appropriate range. The resulting current waveforms are then compared with the IEC reference current.

Figure 4a shows the comparison between the IEC reference current and the tip current in

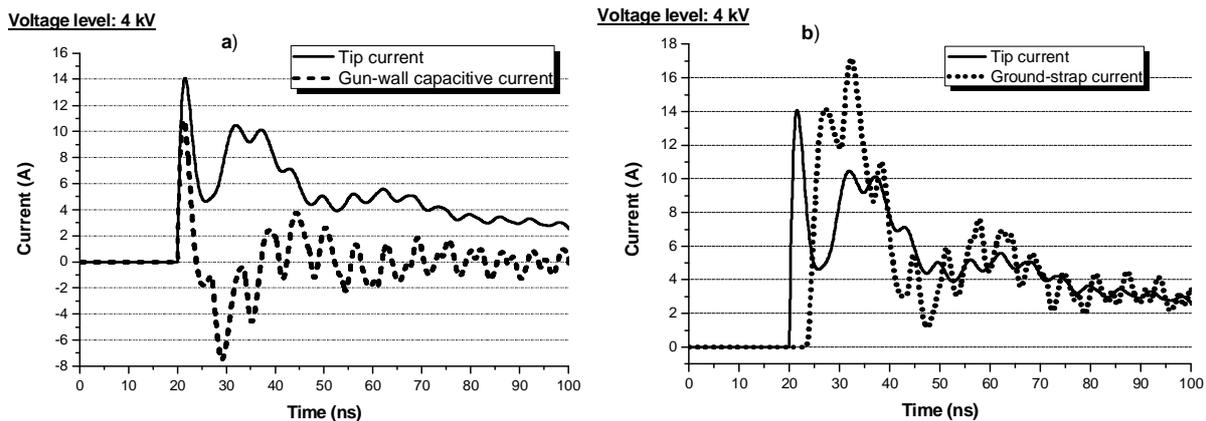


Figure 3. Comparison between a) tip and gun-wall capacitive currents, b) tip and ground-strap currents.

the “basic” configuration. Figure 4b compares the tip current waveforms when  $C_5$  is equal to 10 pF and 50 pF. It can be seen that an intermediate value should allow to approach the reference behaviour in a more acceptable way.

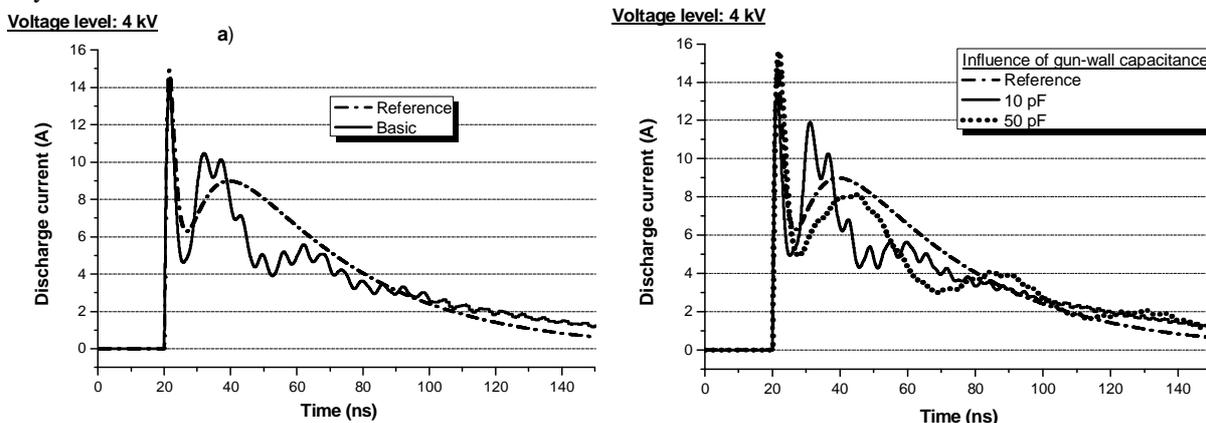


Figure 4. Comparison between a) reference and “basic” tip currents, b) tip currents with  $C_5=10$  pF and 50 pF.

Figure 5 presents the current waveforms in two configurations: a) when the only time delay (TD) of the ground cable is changed with respect to the “basic” value, and b) both the TD and the characteristic impedance ( $Z_0$ ) are varied. These situations correspond, for the first case, to increase both the ground strap inductance and capacitance and, and, in the second case, only the cable inductance. This solution allows to approach both the peak and the tail values of the reference current. These preliminary considerations are just useful to identify possible

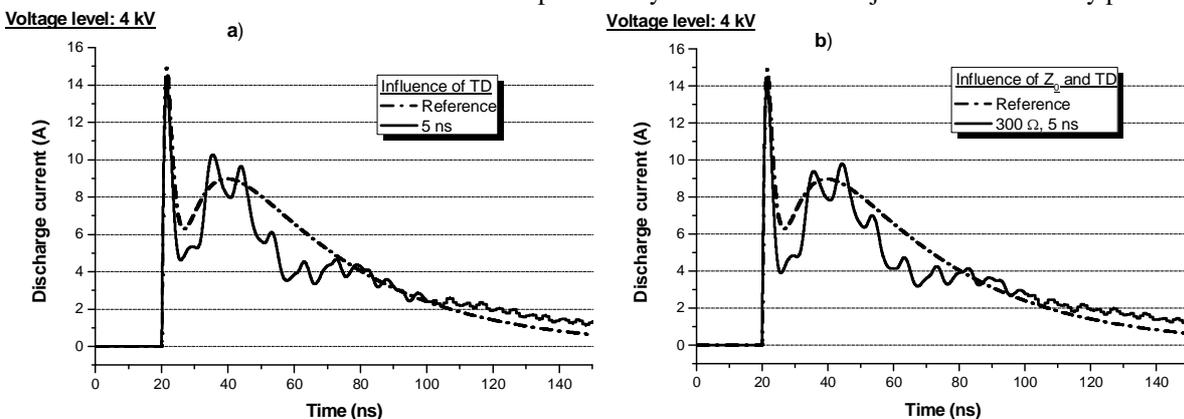


Figure 5. Comparison between a) reference and tip current with  $TD=5$  ns, b) reference and tip current with  $TD=5$  ns and  $Z_0=300 \Omega$ .

geometrical modifications of the measurement set-up, whose stray parameters will be evaluated with satisfactory accuracy by means of the numerical model. A comparison between numerical and experimental results will be performed, in order to validate the proposed model.

As regards the requirement on the charge voltage of  $C_s$  capacitor, this voltage can be measured by means of a high input impedance system. Several high-voltage probes are available on the market for DC measurements and most of them present a 1 G $\Omega$  input impedance. Some tests performed in laboratory proved how a non-negligible load effect can be detected on the voltage across  $C_s$ , whose drop is about 5%. The INRiM reference measuring system consists of a high input resistive divider, with 10 G $\Omega$  impedance and 1/10000 ratio (Fig. 6), whose output voltage is measured by means of high resolution multimeter. The traceability of this system can be ensured by determining the scale factor (factor by which the measuring instrument output is multiplied in order to determine the measured value of the input quantity) at 1 kV. The input voltage is supplied by a DC calibrator and the scale factor is obtained as the ratio between the input and the output voltage. By means of a direct comparison with the INRiM 100 kV HVDC (high voltage DC) reference measuring system [9] along the voltage range (1-25 kV), the linearity of the complete measuring system can be evaluated. The effect of temperature and/or humidity on the divider ratio is evaluated at a single input voltage (1 kV) by placing the divider in a climatic chamber. In this case the input voltage is provided by a voltage calibrator.

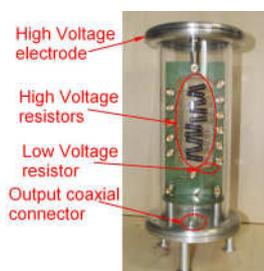


Figure 6. The 10 G $\Omega$  resistive voltage divider.

## V. Conclusions

This work shows the strong influence of some stray parameters on the discharge current waveform and proposes an investigation of their effects through the development of a suitable numerical model. Next step will be to carry out an experimental activity in order to validate the modelling results and to improve the divider performance (e.g. load effect).

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