12th IMEKO TC4 International Symposium
Electrical Measurements and Instrumentation
September 25–27, 2002, Zagreb, Croatia

STUDY ON CERTAIN PARAMETERS INFLUENCING REPEATABILITY AND COUPLING IN ESD TESTS

Alexandru Salceanu, Valeriu David and Liviu Breniuc

Faculty of Electrical Engineering, Technical University of IASI, ROMANIA

Abstract – The main target of our approach is to store (using a good 500 MHz scope with connectivity facilities and a complex experiment set-up recommended by IEC) more than 100 ESD discharge waveform, in order to be compared and to identify the basic factor of influence for the so much disturbing rising slope, important for modelling, prediction, repeatability and timesaving experiments.

Keywords: ESD, rise-time, reproducibility

1. BACKGROUND

Usually, ESD current waves vary largely and to a certain extent, they are difficult to repeat and predict (even if we regard the test conditions as being identical). This variability is considered "statistical". The most upsetting effect of the discharge experience is the very high rate of rise of current and field. The duration of the event is no more than a few nano-seconds but the current speed of variation comes up to 10^{10} amps per second, (corresponding field rate of change could be greater than 1kV/m per nanosecond or 10 A/m per nanosecond). So, the problem is the current rise time. Though the ESD pulse has habitually low energy, the bandwidth is extremely wide (for 0,7ns rising slope, the bandwidth moves towards 500MHz), and the coupling potential through radiation is very significant. For instance, a loop formed by the ESD generator, the DUT, the ground reference plane and a return strap is quite customary. The first "spike" of the discharge, (frequently carrying 10% of the whole pulse energy), could be more damaging to the operation of fast digital equipment than the following bulk discharge, which may have its own rise time of only 5-15 nanoseconds [1]. The upper limit frequency of the interference threat on sensitive circuitry presents differences up to a factor of ten.

2. THE PROBLEM TO BE DEALT

To perform ESD-immunity tests, an ESD-pulse has to be injected to the device under test by a so-called ESD-gun, designed to work in both circumstances: air and/or contact discharge, fig1.

Calibration of this specific "gun" is only the first (compulsory) step and the injected pulse has to be in accordance with the parameters prescribed in the standards. It is important that the calibration of the ESD-gun accurately determines the pulse parameters and that the uncertainty on these parameters might be also known [2]. Even if the calibration is accomplished, the actual current waveform is complex and depends on many types of variables. Finally, the major variations result from a deterministic distribution among just a few basic wave types [3]. The principal variables controlling this distribution are:

- effective electrode geometry,
- high voltage on the "intruder",
- speed and angle of the approaching advance of the intruding mass toward the victim,
- effect of the distributed circuit reactance,
- air conditions (mainly relative humidity, but also temperature and pressure),
- other environmental conditions (surface of the DUT, layout of the ground lead between gun and DUT and also, the real person carrying out the test).

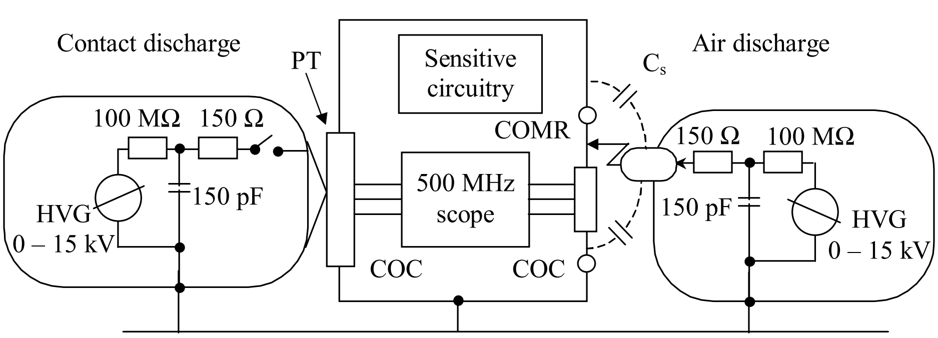


Fig.1 The practical set-up configuration for all the tests performed

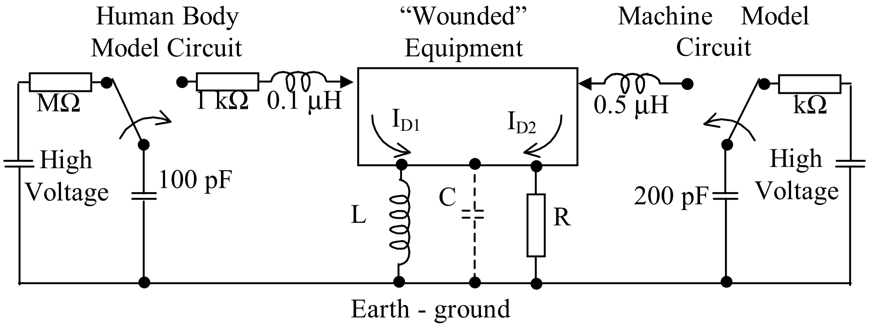


Fig.2 Assuming both human body and/or machine discharge models

In essence, the real problem is the complex interaction of all these variables, presenting totally non-linear transfer characteristics and so supporting the well spread assertion that ESD current waves are unrepeatable. Even if the approach speed is controlled (by large practice, automated motion or good vacuum relay) and the real geometry of the intruding mass electrode (finger tip, ring, key, screwdriver, wrist metallic bracelet) could be monitored and many attempts have been accomplished, the reproduction of an express current shape (and the corresponding potential of interference) is still challenging.

3. TEST SET-UP

We proposed to respect the conditions stated in IEC 61000-4-2, [4]. As ground reference plane we used a 0,6 m^2 aluminium foil (0,5 mm thickness). Both methods of discharging the static accumulation were performed and summarized in fig.1 (air and contact discharge methods are not alternatives, but complementary).

Fig.2 joins the two mostly used and accepted discharging models: human and machine ones. Chronologically speaking, the Human Body Model (HBM) is the first (dating since the nineteenth century) ordinary used for classifying device sensitivity to ESD. In essence, is modelled the discharge from the fingertip of a standing person delivered to the device, by a 100 pF capacitor discharged through a switching component and a 1000 Ω series resistor into the component, limiting the discharge current.

A tested advantage of this model is its capability of accepting automated tests. The DUT is placed in the test system and contacted through a relay matrix. ESD stress is applied and the post stress I-V current traces are examined to see if the devices fail. In our attempts we improved the automated HBM test methodology: the number of zaps per stress level and polarity has been reduced from 3 to 1, while the minimum time interval between zaps has been reduced from 1 second to 300 milliseconds.

Another technical change was a revision in the HBM tester specifications. The maximum rise time for an HBM waveform measured through a 500 Ω load was increased from 20 to 25 nanoseconds. The test equipment manufacturers may build high pin count testers that typically have a higher parasitic test board capacitance slowing down the 500 Ω waveform.

Dealing with machine model (MM), we have to take into consideration that in "human" environment, a personnel is compulsory accompanied by tools (screw-drivers, for instance, are most usual). The Machine Model finally represents a HBM in the worst case: a higher (200 pF) capacitor discharged (quasi) directly into a component, the series resistor being neglected.

The ESD Association standard "ESD STM5.2: Electrostatic Discharge Sensitivity Testing - Machine Model" uses the same test equipment, excepting the test head. Due to the missing of 1 kΩ discharging resistance, the series inductance becomes the dominating parasitic element limiting and fixing the oscillating machine model waveform. The series inductance is indirectly defined through the specification of various waveform parameters.

These model are used in ESD Association standard ESD STM5.1: "Electrostatic Discharge Sensitivity Testing - Human Body Model and Machine Model", being accepted by the most certified authorities in the domain.

Another option to be considered is the Charged Device Model, published by ESD Association in 1999, under the code ESD STM5.3.1: Electrostatic Discharge Sensitivity Testing - Charged Device Model. The point of view is quite different comparing to the previous two models. Now, the sense is somewhat reversed: the device itself is electrostatic charged and then the possible (fast) discharge is towards the metallic enclosure (for instance). It is not obvious, but the discharge from the DUT to the metallic chassis proves to be in some situations more harmful than the standard discharge (from the object to the device), the so-called HBM. The most disturbing is the peak discharging current, reaching several tens of amperes, due to its very short duration.

Harmonising the standards and the models, in the experimental set-up, the human body was modelled as a 150 pF capacitor charged to the voltage supplied by the High Voltage Generator (HVG) and discharged into the DUT through a 150 Ω resistor and a discharge "head" which simulates the dimensions of a pointer finger. C_s are the distributed stray capacitance. The return strap from the charged capacitor to the Aluminium plane completes the return path. For the scope visualization of the waveforms, we used a coaxial measuring resistor, COMR, inserted in the

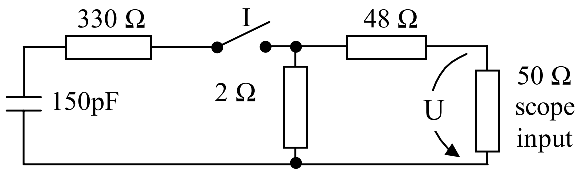
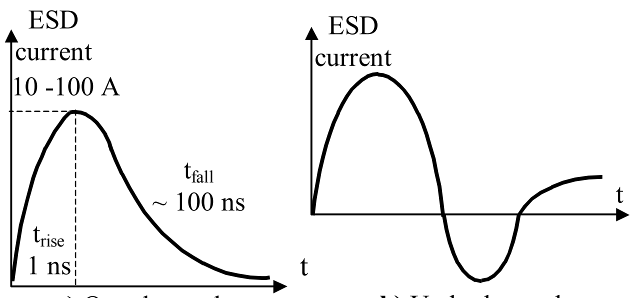


Fig.3. The DC-model for easy determining the current

wall of the DUT, [5]. For maximum repeatability (air discharge) the finger should come up to the DUT fast and perpendicular to the surface. For better reproducibility, the contact discharge method is advisable. The test probe is in direct contact with the DUT and the test discharge current is initiated using a high-voltage vacuum switch, V.S. PT in fig.1 means "Pellegrini type target", special designed for calibration of ESD-guns, [6]. It consists of a 2 Ω resistor across which the pulse is applied and a 48Ω resistor in series with the connection to the measuring oscilloscope which has an input impedance of 50 Ω. The connection between target and oscilloscope is realized with a coaxial cable. This DC set-up is presented in fig. 3, the resistances being chosen with the reason of having the measured voltage (in Volts), equal to the injected current (in Amperes). To accurately determine the high-slope current I from measuring V we need transitions built out of a tapered line which generates a smooth transition from the 18,9 Ω (the characteristic impedance at the injection point of the target) to a N-type connector with a characteristic impedance of 50 Ω. The scope, a troubleshooting one, has 500MHz bandwidth, 2 GSa/s sample rate, provided with powerful digital features: autoscaling, peak detect, waveform storage, automatic measurements as Vpp and frequency. Its complete connectivity (through GPIB and RS-232) is guaranteed by software, measurement storage module and appropriate cable (FFT also available).

4. RESULTS AND CONCLUSIONS



a) Overdamped (High discharging resistance)

b) Underdamped (Low discharging resistance)

Fig.4. Typical current waveforms accompanying an ESD discharge

Starting from the "didactic" shape, shown in fig.4, we acquired analysed and processed more than 100 (scope) waveforms, for different test parameters and configurations:

- the air discharge and the contact discharge;
- the slow discharge mode and the fast one (initial spike), focussed on the spark physical mechanism; beneath the expectations, we observed that, at high charging voltages (6-7 KV), the discharge is 2-3 times slower than at lower charging voltages (1-2 KV);
- the ground strap layout (fixing the inductivity); a lower inductivity, due to a shorter length of the ground connection involves 0nly a 10% increasing in the discharge current;
- human and furniture discharge (optional metallic tool);
- relative humidity from 30% till more than 50%; At a relative humidity of 28%, and the discharge voltage of 5KV, the first steep edge was at 18,2 A. For the same electrostatic voltage, but the relative humidity of 47%, the corresponding steep edge value decreased with about 19%.
- charging voltage from 1kV till 15kV;
- sharp electrode and 2,6 and 10 mm ball electrodes; While the successive discharge with a ball type electrode gave quasi-similar forms for slow and fast approach, the variation with the (fourth finger) ring discharge are more significant. From the current amplitude point of view, an ordinary wedding ring "discharging electrode" was comparable with the 10mm diameter ball tip, the peak current at 5 kV being about 21A, the rising slope >22A/ns;
- various approaching speeds towards the "victim" device.

An improvement of the repeatability of the rising part of the discharge waveform (the most disturbing ESD event), by controlling the basic factors of influence is strongly desired for shorter lasting and trustworthy tests, predictable and realistic modelling attempts.

ACKNOWLEDGMENTS

This work was financed and developed in the framework of the Leonardo da Vinci pilot project with the contract number: RO/98/83550/PI.

REFERENCES

[1] T. Williams, K. Armstrong, "EMC For Systems and Installations", Newnes, Oxford, UK, pp. 258-260, 2000.
[2] M. Lutz, O. Frey, W. Taylor, "Human ESD: the Phenomena, their Reproduction and some Associated Problems", IEEE International Symposium on EMC, pp. 461-466, 1986.
[3] P.Richman, "Classification of ESD hand/metal current waves versus approach speed, voltage, electrode geometry and humidity", IEEE International Symposium on Electromagnetic Compatibility, pp. 451-460, 1986.
[4] IEC 61000-4-2, "EMC-Part4-Testing and measurement techniques- Electrostatic discharge immunity test", 1995.
[5] B. Daout, H. Ryser, "The reproducibility of the rising slope in ESD testing", IEEE International Symposium on Electromagnetic Compatibility, pp. 467-478, 1986.
[6] W.De Ketelaere, L.Martens, Y.Braem, Y.Vlietinck, "Calculation of the ESD-pulse parameters and associated uncertainty for ESD-gun calibration", IEEE International Symposium on EMC, pp. 449-452, 2000.

Authors: Professor Alexandru Salceanu, Faculty of Electrical Engineering, Technical University of IASI, Bd. Dimitrie Mangeron No 53, IASI 6600, ROMANIA, +40 232 278680, +40 232 237627, asalcean@ee.tuiasi.ro
Associate Professor Valeriu David, Faculty of Electrical Engineering, Technical University of IASI, Bd. Dimitrie Mangeron No 53, IASI 6600, ROMANIA, +40 232 278680, +40 232 237627, valdavid@ee.tuiasi.ro
Professor Liviu Breniuc, Faculty of Electrical Engineering, Technical University of IASI, Bd. Dimitrie Mangeron No 53, IASI 6600, ROMANIA, +40 232 278680, +40 232 237627, lbreniuc@ee.tuiasi.ro