Circuital and Numerical Modeling of Electrostatic Discharge Generators

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***Abstract*— The paper provides two accurate and efficient models of electrostatic discharge (ESD) generators which permit to reproduce the discharge current in the contact mode taking into account the load effect. The first model is based on a circuit approach and is suitable to be implemented in any commercial circuit simulator. The second model is based on the numerical solution of the field equations by using the commercial numerical code Microwave Studio (MWS) based on the finite integration technique. The validation of the proposed circuit and numerical models is carried out by comparison with measurements.**

Keywords: Electromagnetic compatibility (EMC), electrostatic discharge (ESD), numerical modeling, immunity.

I. INTRODUCTION

Electrostatic discharge (ESD) generators are widely used for testing the immunity of electronic equipment and permit to reproduce typical human-metal ESD events. To ensure the reproducibility of test results, the majority of available ESD generators are built in compliance with the specifications of the IEC 61 000-4-2 standard and its second edition which is still under discussion [1]. The immunity prediction against ESD events by experimental activity is not considered to be very practical in particular when the evaluations is required for different design choices.

For this reason, in the last years a great concern has been addressed by many researches to the numerical simulation of ESD events [2]-[5]. A numerical model based on the FDTD method adopting impedance network boundary conditions was proposed in [2] to predict the ESD effects inside penetrable conductive enclosures. Recently, numerical models based on the finite difference time domain method of typical electrostatic discharge (ESD) generators have been presented in order to simulate current discharge and radiated fields [3], [4]. In the past an analytic approach based on transmission line formulation was proposed to predict voltage induced into a coaxial cable by an ESD discharge [5]. In [5] the ESD was simulated by a current source without taking into account the load effect of the ESD generator. As the same authors recognize, this procedure brings to an overestimation of the subsequent peaks of the induced disturb.

The prediction of the immunity by modern software tools based on circuital or numerical approaches requires accurate models for the ESD generator suitable to account for the load effect of the generator.

This paper provides two accurate models of the ESD generator that allow modeling the discharge current in the contact mode taking into account the load effect.

In the first model the ESD generator is modeled by an electric circuit suitable to be implemented in any commercial circuit simulator.

The second model is based on the 3D numerical simulation of the ESD generator by the commercial tool Microwave Studio (MWS) based on the finite integration technique [6].

The validation of both the models is made by comparison with the measurements by using the test setup for current calibration reported in [1] and shown in Fig. 1. This test setup models the ESD event on a conductive wall. The flat cable used as ESD strap is connected to the metallic wall where the discharge occurs.

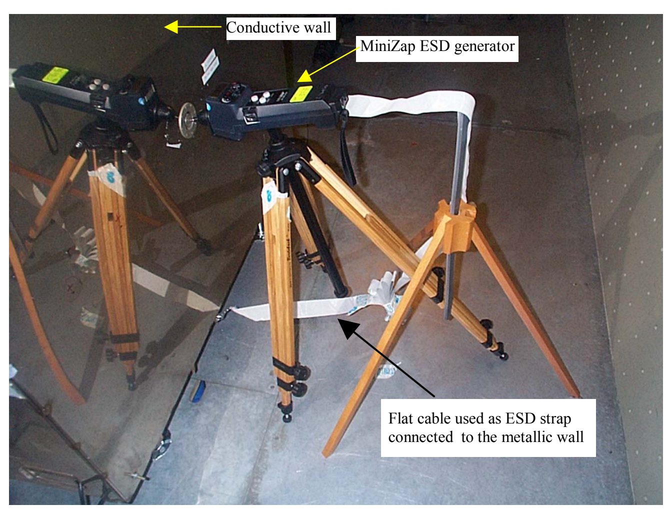

Figure 1. Test setup used for ESD current calibration.

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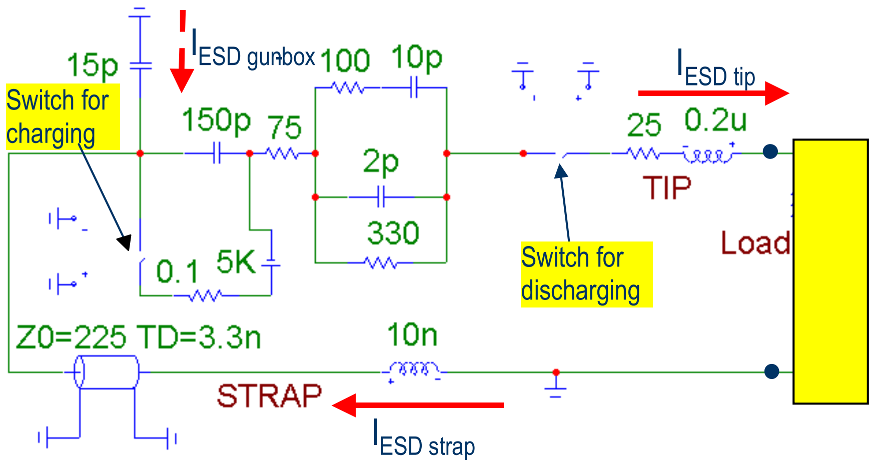


Figure 2. Spice equivalent circuit of a typical ESD generator.

II. MODEL OF ESD GENERATOR

A. Equivalent Circuit Model

The purpose of an ESD generator is to reproduce typical human-metal ESD. Considering this, a suitable circuital equivalent model could be the one shown in Fig. 2. This circuit model can be easily implemented in any SPICE based circuit simulator [7]. The lumped circuital elements are chosen as typical values that simulate the body and the arm effects of the person that causes ESD. In the circuit model of Fig. 2 there are two switches: the first one (on the left side) is used to charge the 150 pF capacitor at the typical voltage of 5 kV; the second switch (on the right side) provides the discharge. The flat cable used as ESD strap connected to the ground is modeled by the series connection of the lossless transmission line characterized by characteristic impedance 225 Ω and propagation time 3.3 ns, and a 10 nH inductance which models the wire used to connect the flat cable with the metallic wall. The 15 pF capacitance models the capacitive coupling between the ESD gun and the metallic wall (see the experimental setup shown in Fig.1). The ESD tip is modeled by the series of a 25 Ω resistance with the 0.2 μH inductance. It should be noted that the load represents the impedance of the metallic wall, and in the considered simulation is given by a 2 Ω resistance.

B. Full-Wave Model

The ESD generator is modeled by using the commercial numerical code Microwave Studio (MWS) based on finite integration technique [6]. The model, shown in Fig. 3, contains dielectric parts, metallic parts and lumped circuital elements which permit to reproduce the physical form of a typical ESD generator and the reference discharge current proposed by IEC 77b [1], [3].

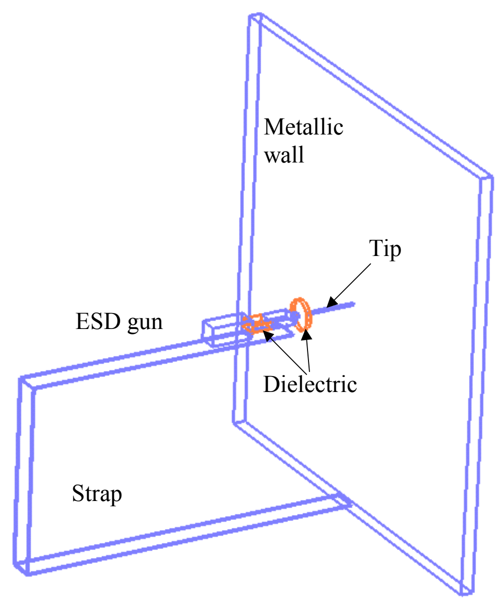
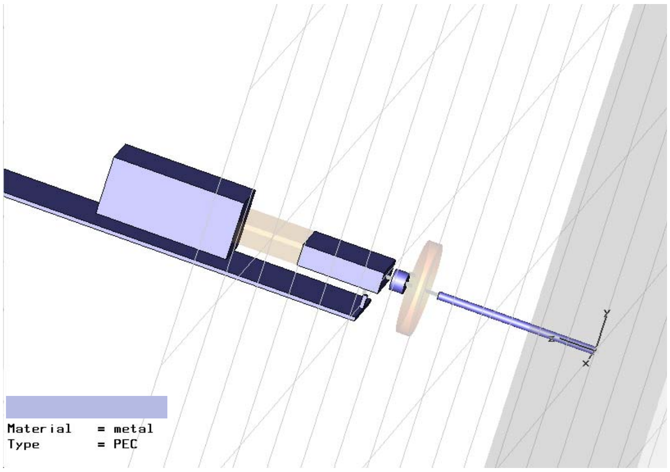
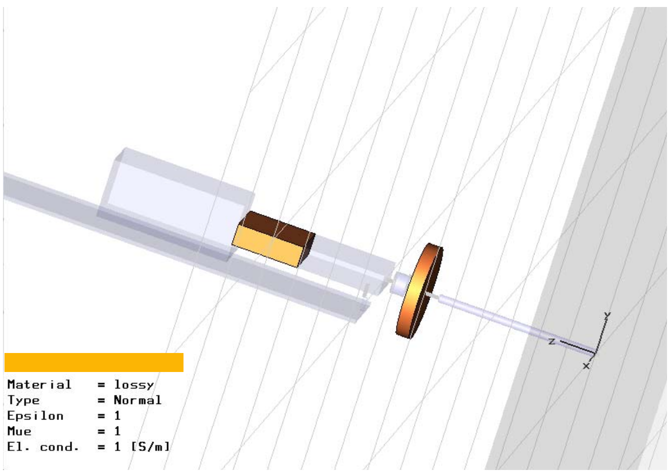


Figure 3. The ESD simulator modeled in MWS.

The geometrical configuration of the ESD generator adopted for the numerical simulation is similar to that of the MiniZap gun. Details on the material properties used to model the different part of the ESD gun are shown in Fig. 4. The lumped circuit elements adopted in the MWS model are shown in Fig. 5. The model is excited at Port 2 (see Fig. 5) by an ideal current source with 25Ω assuming a step rise-time of 1ns to reproduce the actual slow charging, switching and rapid discharge process of an ESD generator.



(a)



(b)

Figure 4. Material details of the ESD simulator model in MWS: perfect electric conductive (a) and lossy dielectric (b) regions.

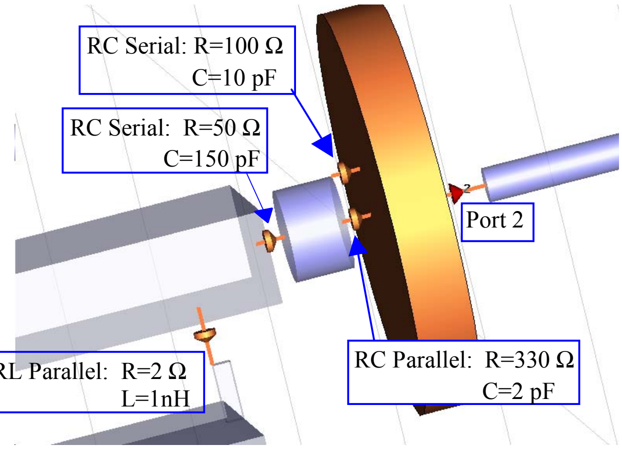


Figure 5. Lumped element network and port excitation used to reproduce the physical form of a typical ESD generator and the reference discharge current proposed

III. VALIDATION OF THE ESD GENERATOR MODELS

To validate the proposed models, current on the tip and strap of a commercial ESD generator called MiniZap where measured by using the setup for current calibration reported in [1] and shown in Fig. 1. The wall is a side of a shielded enclosure in which a target is mounted to measure currents by an oscilloscope within the enclosure. This configuration permits to avoid the coupling between the ESD event and the instrumentation. All the measurements were carried out at charging voltage of the ESD generator of 5 KV. The experimental setup has been arranged in the shielded room of Italtel S.p.A.

The tip and strap current obtained by the two proposed models are shown in Figs 6-7. The comparison between the simulation results and the measurements reveals a very good accuracy. Moreover, the following considerations can be done:

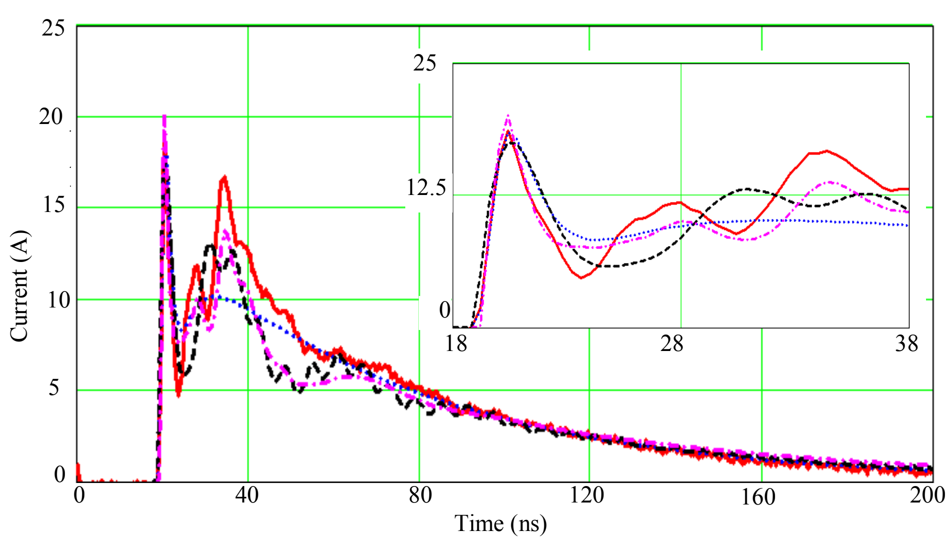


Figure 6. Tip current: measured (solid line); Standard IEC (dot line); SPICE (dashed line); MWS (dashed-dot line).

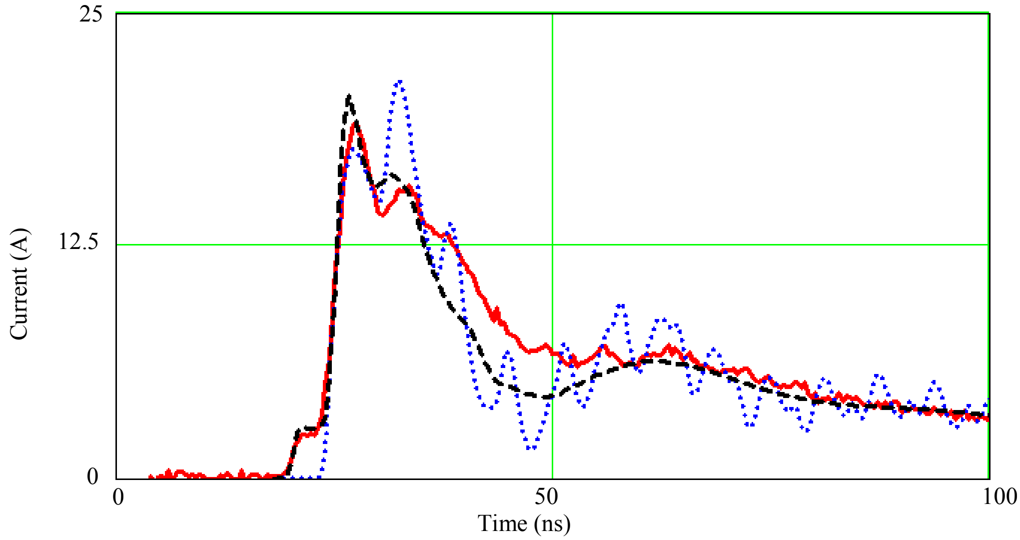


Figure 7. Strap current: measured (solid line); SPICE (dashed line); MWS (dashed-dot line).

- The first fast rise time (less than 1ns) is reproduced and match well with the reference IEC current.
- The measured and simulated waveforms after the first peak follow quite well with slight oscillations the reference IEC current. This is mainly due to the length and orientation of the strap.
- The current on the strap has slower rise time than the current on the tip. This is due to the capacitance between the ESD generator and the environment (the metallic wall in this case, see the 15pF of Fig.2) that permits an alternative path for the first peak of the ESD current.

In order to verify the generality of the developed models in terms of reproducibility of test results even using different ESD gun, the tip current has been measured several time by using the MiniZap gun (Fig. 8a), and by using the DITO gun (Fig. 8b). The measured tip currents shown in Fig.9 show that there is very little difference between two measurements performed with MiniZap gun and with that obtained using DITO gun.

(a)

(b)

Figure 8. ESD generators: MiniZap (a) and DITO (b) guns.

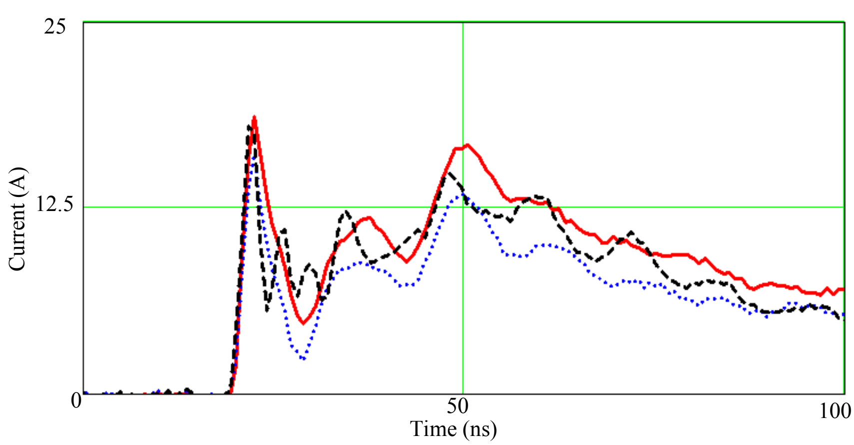


Figure 9. Measured tip current: MiniZap (solid line); MiniZap 2 (dot line); Dito (dashed line).

IV. CONCLUSION

Circuit and numerical models of the ESD generator have been proposed and discussed. The circuit model is suitable to be implemented in any commercial circuit simulator such as SPICE. The numerical model is based on the 3D simulation by the commercial tool MWS based on the finite integration technique. Both the models allow the accurate simulation of the discharge current in the contact mode taking into account the load effect. The comparison of the simulation results with measurements have revealed a very good accuracy.

The proposed models are of great interest since they represent an important item in the development of software tools suitable for the prediction of ESD immunity, especially during the design stage.

ACKNOWLEDGMENT

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REFERENCES

[1] 77B/378/CDV, *"IEC 61000-4-2: EMC-Part 4-2: testing and measurement techniques- ESD immunity test"*, 2003-04-11.

[2] F. Maradei, M. Raugi, "Analysis of upset and failures due to ESD by the FDTD-INBCs method", *IEEE Trans. Industry Applications*, vol. 38, no. 4, Jul./Aug.2002, pp.1009-1017, *James Melcher Price Paper Award*.

[3] Kai Wang, D. Pommerenke, R. Chundru, T. Van Doren, J. Drewniak, A. Shashindranath, "Numerical Modeling of Electrostatic Discharge Generators", *IEEE Trans. on EMC*, vol.45, no.2, May 2003.

[4] S. Caniggia, F. Centola, D. Pommerenke, Kai Wang, T. Van Doren, "ESD Excitation Model for Susceptibility Study", *IEEE EMC Symp.*, Boston, 18-22 Aug. 2003.

[5] G. Cerri, R. De Leo, V. Mariani Primiani, "ESD Indirect Coupling Modeling", *IEEE Trans. on EMC*, vol.38, no.3, August 1996.

[6] Microwave Studio, Computer Simulation Technology (CST), www.cst.de

[7] Spectrum Software, 1021 S. Wolfe Road Sunnyvale, CA 94086, www.spectrum-soft.com