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ELECTROSTATIC DISCHARGE PHENOMENON REPRESENTED BY THE MATHEMATICAL AND ELECTRONIC MODELLING OF HUMAN BODY MODEL

BY

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Abstract. The Electrostatic Discharge (ESD) phenomenon represents the most common mode of failure of the electronic circuitry.

The present paper is focused on the mathematical and electronical modelling, respectively simulation of the Human Body Model (HBM). In order with the obtained information, it can be performed a few protective circuitry to reduce or to eliminate the effects of the electrostatic discharges upon the electronic circuitry, provided by HBM.

All the simulations were performed in OrCAD PSPICE produced by Cadence Company.

Key words: electronic circuitry; electrostatic discharge phenomenon; Human Body Model.

1. Introduction. Electrostatic Discharge Phenomenon

The electrostatic charges are created by the contact and separation of two materials (Hong Luo *et al.*, 2011). Electrostatic discharge phenomenon represents the transient current flow compensating the charge unbalance or represents the transfer of electrical charge between two bodies at different

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potentials, through direct contact or induced electrical field (Esmark *et al*., 2003). Both of the main sources are provided by people and equipment. The shape of the produced discharge current varies in shape, amplitude, time rising (ESD Association, 2001).

The ESD phenomenon represents one of the most important threats in electrical industry. It can modify significantly the electrical properties and characteristics of a semiconductor device, degrading or destroying it (Manolică, 2011).

Human body model is one of the oldest and known model to simulate the electrostatic discharge. Often, electrostatic charges are established at the contact and the separation of two materials. The most common cause of the damages created by the electrostatic discharges consists in directly transfer of the electrical load from the human operator to the electric or electronic equipment. This phenomenon is illustrated in Fig. 1, through a human body and a dispositive under test (DUT), both connected to the ground (GND).

Suddenly, discharging from human body to the device leads to the appearance of a high voltage or high current on the device. This phenomenon causes an irreversible destruction of the circuit or of the entire equipment.

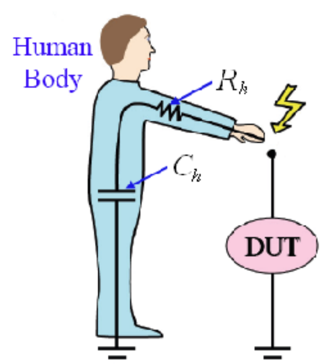

Fig. 1 – Electrostatic discharge produced by the human body touching the equipment.

Human body can be modeled through a capacitor and a resistor. An electrical schematic design of the human body is presented in Fig. 2 and represents the most common model used to test the sensibilities of the equipments to the appearance of ESD. The circuit from Fig. 2 represents the Human Body Model, the electronic model. The circuit consists in a capacitor (C = 100 pF) which is discharging through a switch on a discharging resistor (R_d = 1.5 kΩ).

The capacitor C_h models the human body capacity, and the resistance of the arms of the human body is represented by R_h.

The electronic schematic of HBM can be represented by *RLC* circuits, varying some parasitic circuit elements (Manolică, 2011).

Frequently, HBM events occur at 2…4 kV, hence protection levels of this range are necessary (Amerasekera & Duvvury, 2002). The value of the discharge current represents the peak current for high-voltage power supply (Bicleanu *et al*., 2012). Time domain of the discharge current it is very small, between 100 and 200 ns, with a small rise of time, less than 10 ns. The typical value of the fall time is $\tau = R_d C$.

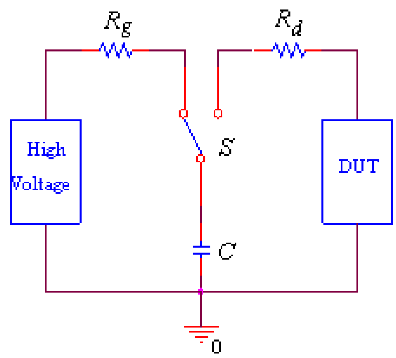

Fig. 2 – The electronic circuit of the Human Body Model.

2. OrCAD Software Used for Designing the Electrical Schematics

To perform the simulations for HBM was used a software package, named OrCAD PSPICE, which is produced by Cadence Company. This model of software helps the engineers to develop electronic circuitry and to test them. The modules included in the program are for schematic entry, design simulation, data analysis, physical layout and final verification (Dabral & Maloney, 1998).

In the present paper were developed a few software simulations to observe the effects of electrostatic discharges, provided by the human body model.

3. Experimental Data and Results

The classical standardized model for ESD phenomenon is represented by Human Body Model. The schematic design is illustrated in Fig. 2. In Fig. 3 is shown the discharge current waveform when the supply power is fixed to 2 kV and the time domain is 200 ns. The value of the discharge current is calculated with the expression

$$I_p = \frac{V_{\text{ESD}}}{R_d + R_{\text{DUT}}} \ . \tag{1}$$

The current associated to the ESD has an ideal waveform presented in the IEC/EN 61000-4-2 standard. The modelling of the current waveform is based on the adding or the differentiation of exponentials (Fotis & Gonos, 2006). The formula contains time and current constants. The relation that permits to calculate the current value for discharge current is

$$i_1(t) = i_0\left(e^{-t/t_1} - i_2 e^{-t/t_2}\right). \tag{2}$$

In relation (2) i_0 represents the maximum value (peak value) of the current, and t_1 and t_2 are the rise and the fall time of the current pulse, respectively.

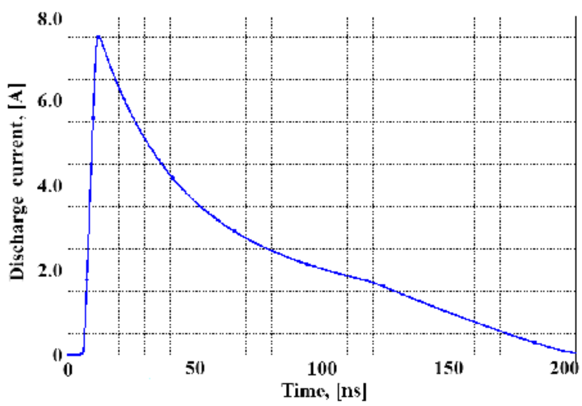

Fig. 3 – Discharge current for a 2 kV power supply for a 200 ns period.

Fig. 4 shows the graphical representation of the relation (2). The values of the constants are: i_0 = 7.50 A; t_1 = 3.9 ns; t_2 = 92 ns. The period time of the simulation is 100 ns.

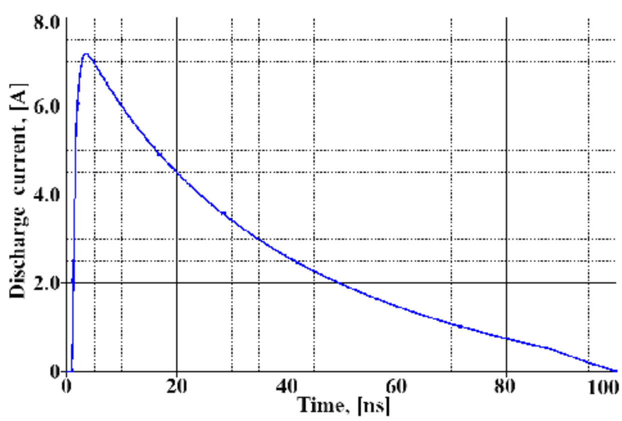

Fig. 4 – Typical discharge current waveform corresponding to the eq. (2) for 100 ns time domain.

The high voltage power supply (Fig. 2) provides a voltage with 2 kV amplitude, to obtain a value of the current, approximately of 7.5 A. The capacitor C is charged up to a certain voltage (Bicleanu *et al*., 2012), through the charging resistance, $R_g \geq 1$ MΩ. After the capacitor is fully loaded, it is removed from high voltage supply and the load resistor will be connected in series with the discharging circuit and the DUT; the discharging phenomenon is performed by operating of a switch.

4. Obtained Results

The paper presents two cases of the discharge current waveform, related in Figs. 4 and 5.

First case (Fig. 4) indicates that the waveform of the discharge current has a small time rise, about 3.9 ns (< 10 ns, which is a typical value for HBM time rise).

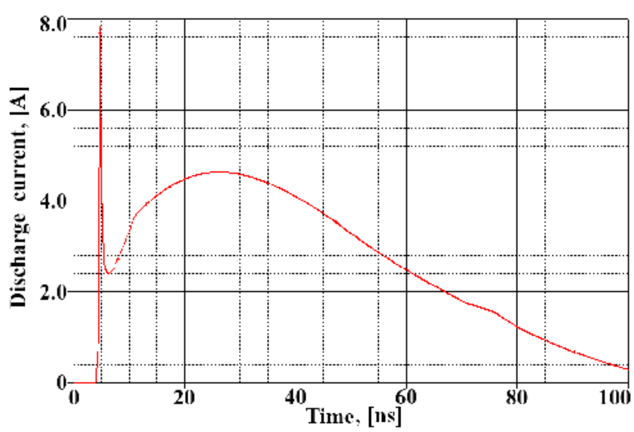

Fig. 5 – Discharge current waveform according with the standard IEC/EN 61000-4-2.

Second case (Fig. 5) shows a waveform with two increases of discharge current. The first one represents the highest increase represented by the peak current, with a value of 7.75 A. After this increasing, it appears a second increasing, with a smaller value, of 4.25 A. This shape of the discharge current waveform is closer to the standard waveform described in the IEC/EN 61000-4-2 standard.

The specific values of simulated parameters of the HBM are related in Table 1. The parameters presented in Table 1 are peak current (the maximum value of the discharge current, for 2 kV applied voltage), the current values corresponding to 30 ns and 60 ns period time and the time rise calculated for both cases.

Table 1
Characteristic Parameters of the HBM

Case I (Fig. 4)			Case II (Fig. 5)		
Applied voltage 2 kV					
Current, [A]			Current, [A]		
I_{peak}	$I_{30\ ns}$	$I_{60\ ns}$	I_{peak}	$I_{30\ ns}$	$I_{60\ ns}$
7.5	4.5	1.9	7.75	1.8	1.48
Rise time, [ns]			Rise time, [ns]		
$t_1 = 3.9$			$t_1 = 6.7$		

5. Conclusions and Future Work

The ESD phenomenon has a major impact upon the electronic industry. All the performed tests are very important in the evaluation of the protection circuitry in electronic devices area.

An analytic method to determine the discharge current waveform provided by human body is presented. The analytic method is based on the mathematical expression of the discharge current. As variables it contains the maximum value of the discharge current or peak current (i_0), respectively the rise time (t_1) and the fall time (t_2). With the obtained results it can be described the transient phenomena appeared in electronic industry and their effects upon the electronic circuitry. In the same manner it can be performed a few protective circuitry to reduce the ESD's effects.

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FENOMENUL DE DESCĂRCARE ELECTROSTATICĂ REPREZENTAT PRIN MODELAREA MATEMATICĂ ŞI ELECTRONICĂ A MODELULUI CORPULUI UMAN

(Rezumat)

Fenomenul de descărcare electrostatică (DES) reprezintă modul cel mai frecvent de defectare a circuitelor electronice.

Lucrarea este concentrată pe modelarea şi simularea matematică şi electronică a modelului corpului uman (MCU). În urma rezultatelor obţinute se pot realiza o serie de circuite de protecţie, în scopul reducerii sau eliminării efectelor descărcărilor electrostatice asupra circuitelor integrate, provenite de la corpul uman.

Modelările, respectiv simulările MCU, au fost realizate în mediul OrCAD PSPICE produs de Compania Cadence.