Journal of ELECTRICAL ENGINEERING, VOL 63. NO 7s, 2012, 126-129

MEASUREMENT OF MAGNETIC WAVE SHAPE OF INDIRECT ELECTROSTATIC DISCHARGE

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This paper deals with analysis of influence of distance from electrostatic discharge point upon the shape of magnetic component of electromagnetic field generated by the discharge. Measured waves are also influenced by several unknown factors. So the equivalent parameters of time wave shapes are calculated by nonlinear regression. The residuals of regression are also shown. The aim of this work is to find the changes of H- component waves with distance from electrostatic discharge point.

Keywords: electrostatic discharge, magnetic wave, ESD gun, induced voltage, H-field spectra

1 INTRODUCTION

Electrostatic discharge (ESD) is a transient event, which implies high current, fast rise times and has a destructive character for sensitive electronic modules. Most of electronic components are very sensitive to ESD induced effects, and because of that it is important to prior determine their susceptibility with respect to this phenomenon. Miniaturized electronics involves high risks to ESD due to their small sizes and high operation frequency. ESD immunity testing methods, procedures, ESD gun setup and limits are specified in the EN 61000-4-2 standard [1]. The immunity test against ESD is a part of compulsory tests against disturbing electromagnetic compatibility (EMC) effects. ESD immunity test characterizes the behaviour of electronic components under the stress of ESD in order to insure their reliable operation if in operation are subjected to real level ESD. These discharges give rise to radiated effects, like magnetic and electric fields and conducted effects, like discharge current.

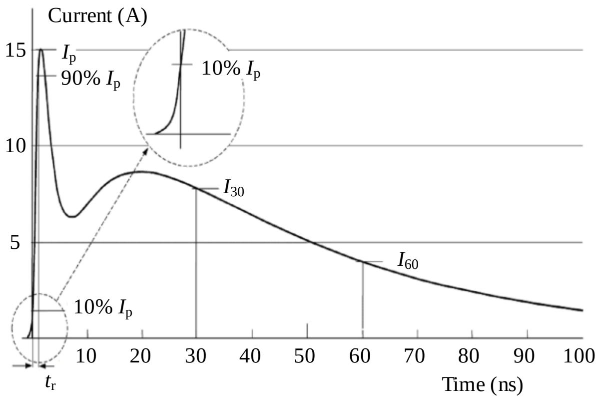

Fig. 1. Ideal waveform of discharge current

ESD events may cause EMC problems leading to undesirable interferences in electronic environment. While the level of electric field involved in ESD can cause electronic circuit malfunction, the involved currents may create voltage drops that affects circuit operation [2]. According to this standard, there are two testing methods: direct discharge and indirect discharge. The indirect one should be performed by contact form due to its relative good reproducibility

As it can be observed from the graphical representation of ideal form of ESD current, illustrated in Fig.1, the current wave has two peaks. First peak is influenced by the parasitic capacitance between the ESD gun and the matellic coupling plane, while the second peak is caused by the ESD gun electrical parameters [3]. The discharge current waveform is influenced by parasitic capacitances and inductances and by the length of the ground strap used to equalize the ESD gun potential.

The international standard specifies also significantly simplified equivalent model of the electrostatic discharge circuit called Human Body Model. The model with numerical values of RLC parameters is presented in Fig.2.

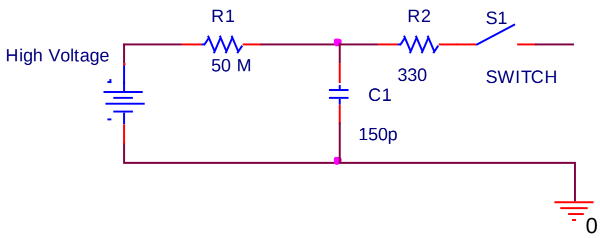

Fig. 2. IEC ESD gun Human Body Model.

According to the above mentioned standard, the discharge current waveform can be approximated using Heidler's equation [1]:

$$i(t) = \frac{i_1}{k_1} \cdot \frac{\left(\frac{t}{\tau_1}\right)^n}{1+\left(\frac{t}{\tau_1}\right)^n} \cdot e^{\frac{-t}{\tau_2}} + \frac{i_2}{k_2} \cdot \frac{\left(\frac{t}{\tau_3}\right)^n}{1+\left(\frac{t}{\tau_3}\right)^n} \cdot e^{\frac{-t}{\tau_4}} \tag{1}$$

where i_1, i_2 are current amplitudes, τ_1, τ_2, τ_3, τ_4 are time constants in ns, n is a constant, while k_1 and k_2 are exponential functions depending on time constants, as can be observed in Eq.(2) and Eq.(3) [4], [5].

$$k_1 = e^{-\frac{\tau_1}{\tau_2}\left(\frac{n \cdot \tau_2}{\tau_1}\right)^{\frac{1}{n}}} \tag{2}$$

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$$k_2 = e^{-\frac{\tau_3}{\tau_4}\left(\frac{n\cdot\tau_4}{\tau_3}\right)^{\frac{1}{n}}} \quad (3)$$

The corresponding values of Heidler's equation parameters are illustrated in table 1, used to obtain the ideal form of discharge current shape.

Tab. 1. Parameters of the nominal IEC pulse

τ_1 (ns)	τ_2 (ns)	τ_3 (ns)	τ_4 (ns)	i_1 (A)	i_2 (A)	n
1.1	2	12	37	16.6	9.3	1.8

2 TEST SETUP FOR H-FIELD MEASUREMENTS

The current produced during ESD generates magnetic fields. This way the measurement of H-field is a valid measurement for assessment of ESD event. Testing configuration for determining the H-field radiated by ESD implies the presence of a grounded metallic plane, a 6 cm diameter H-field loop probe connected to 2 GHz digital storage oscilloscope with real single shot sampling rate of 5 GS/s. The oscilloscope displays the induced voltage in the field probe in peak-to-peak values. Measurements were performed in different points while the ESD gun was kept on a perpendicular direction with respect to the grounded metallic plane. The distances between recording points were 0.1 m and the probe was placed at 5 cm above the metallic plane.

The grounding cable of the ESD gun represents the current return path and influences the current waveform and immunity test efficiency, so its construction, arrangement and length must be according to the international standard EN 61000-4-2.

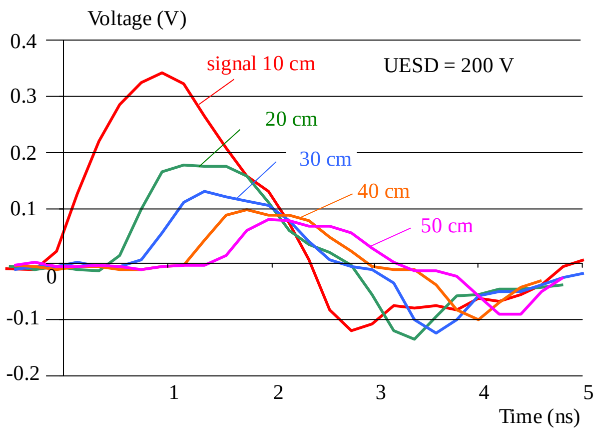

Fig. 3. Time delay between the induced voltages in the sensor.

The H-field measurement principle is based on field probe sensing capability. H-field probe throw its transfer impedance acquires the induced voltage. Then the H-field is obtained by numerical transformation. Induced voltage waves at different distances from the discharge point are shown in Fig. 3. In it the time delay from current pulse can be observed as the distance is changing. The presented waves were obtained by +200 V voltage of ESD, due to current probe saturation limit.

Real H-field waves were determined using integral transformation of induced voltage at +2 kV ESD taking into consideration the field probe transfer function. At higher ESD voltage better signal-to-noise ratio was reached. The H-waves are presented in Fig. 4. There it can be observed that for this loading voltage, in the close proximity from discharge point, the H-field intensity is very high, with a first peak of approximately 26 A/m. The intensity of magnetic field radiated by ESD decreases as the distance from the ESD point is increased.

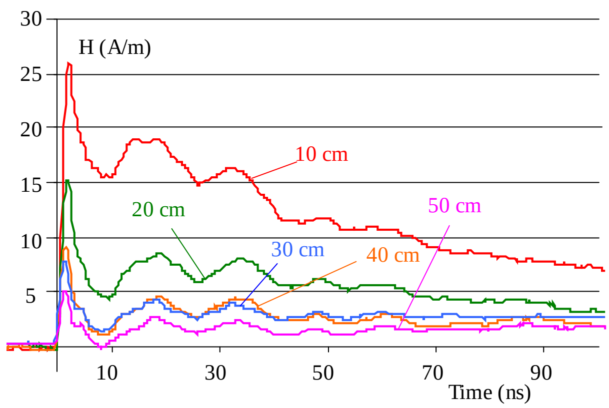

Fig. 4. Magnetic field dependence upon time time at different distances

Since the amplitude of the H field decreases as the distance from ESD point is increased, it can be concluded that electromagnetic interference issues are less significant as electronic circuits are situated far from the discharge point. The shape of H-field wave generated by ESD is also influenced by scattering of electromagnetic wave above metallic plate during and even after ESD. It results in oscilations, which are visible at all waves in given figure.

3 IDENTIFICATION OF INTENDED H-FIELD WAVE

We may suppose that the magnetic component wave shape should copy the waveform of current wave, which is the source of the field. So we may expect that the H-component wave may be expressed by formula similar to Eq. (1). Under this assumption we processed the measured wave by nonlinear curve fitting function (*lsqcurvefit*) of MATLAB environment. An example of measured and fitted curves for 10 cm distance is shown in Figure 5.

To find out the dependence of H-field waveform upon the distance from ESD point we calculated the parameters of Eq. (1) for all measured waves. They are shown in Table 2. Instead of i_1 and i_2 symbols h_1 and h_2 are used. Calculated time constants show good agreement with standard values of ESD current parameters except the τ_4. But its estimation may be affected by offset of the measuring channel, which may have influence upon transformed *H*-waveshape.

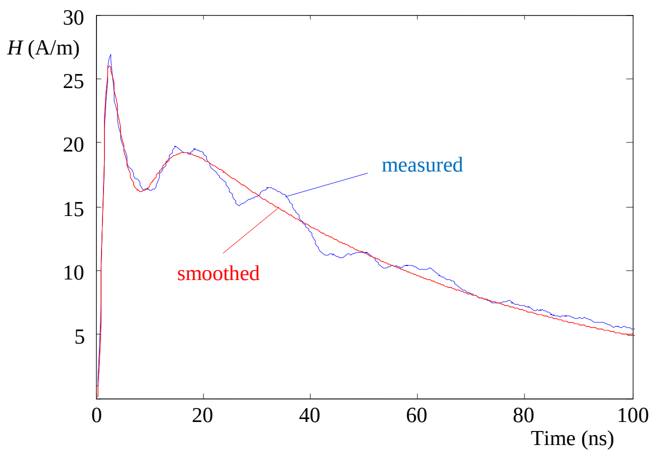

Fig. 5. Measured and smoothed H-component wave for 10 cm distance.

Tab. 2 Parameters of substituing analytical functions of H-field waves

Distance [m]	h_1 [A]	h_2 [A]	τ_1 [ns]	τ_2 [ns]	τ_3 [ns]	τ_4 [ns]	Ratio h_1/h_2
0.1	25.7	16.5	1.54	6.17	11.6	58.8	1.56
0.2	16.2	7.86	1.49	3.25	11.8	58.5	2.06
0.3	10.6	3.92	1.53	2.24	11.8	60.8	2.71
0.4	7.53	2.06	1.52	1.74	12.9	53.5	3.26
0.5	5.72	1.53	1.33	1.80	12.4	76.1	3.66

Except approximation parameters of Eg. (1) the ratio of peak amplitudes h_1/h_2 is placed in the table. Peak amplitudes ratio is rising with distance, which indicates that the slow pulse is more intensively suppressed by distance than fast peak. This fact is important from practical point of view, as the fast rising edge is the most dangerous parameter for electronics.

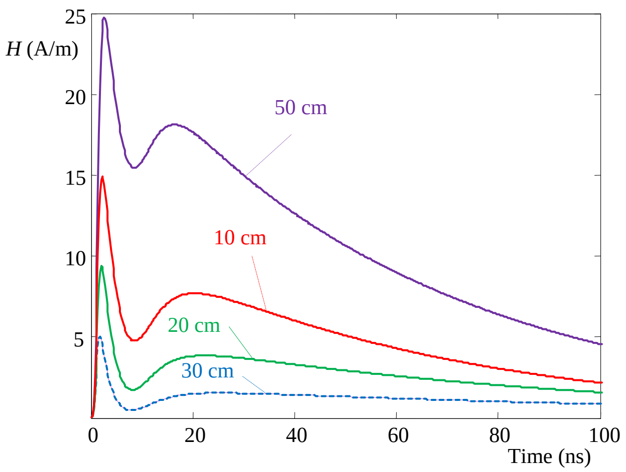

Fig. 6. Smoothed curves of H-component versus time at different distances

H-field waveshapes approximating functions for several distances are shown in Figure 5. There one can see different attenuation of fast and slow pulse parts as the distance is changing.

4 PARASITICS

As it is evident from figure 5 and 6 there are fluctuations on the measured waves. To allow better representation of them the difference between measured and smoothed waves (a residual) is shown in figure 7 for 40 cm distance.

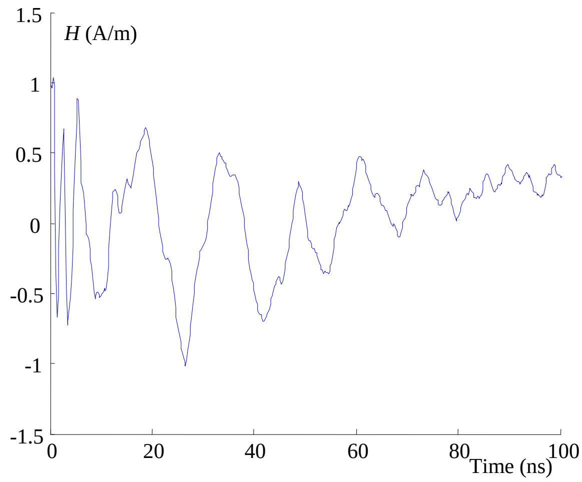

Fig. 7. Residual – difference between measured and smooted curves for 40 cm distance.

There are several sources of oscilating waves in analyzed process. Although it was concluded in [6] that the impedance of ground strap of ESD gun has small influence upon the H-field wave, it was shown that position of ferrite current probe affects the discharging current. This may be the first source of parasitic waves. Then as the wave propagates above metallic plate it is reflected at the edges of plate. The residual shows rather strong periodic dependences with periods of approximately 4 ns and 15 ns. The first value corresponds with the length of grounding strap as well as the width of metallic plate and the second with its length.

5 FREQUENCY CHARACTERISTICS OF MEASURED WAVES

Frequency spectra of H-field component wave, depicted in Fig. 8, shows that:

- slow pulse part has higher amplitudes but narrower bandwidth (less than 80 MHz),
- fast pulse part has lower amplitudes and wider frequency bandwidth (up to 400 MHz).

For 400 MHz the wavelength is 0,75 m and it should be considered that the range of distances is in far field zone, where the wave is attenuated indirectly proportional to distance [7]. While for 80 MHz the wavelength is 3,5 m, what means that our distances are in near field zone, where the wave is more strictly attenuated by distance. This is the explanation of the fact, that slow pulse is attenuated more significantly.

6 CONCLUSIONS

It was shown that the typical parts of ESD current waves (fast and slow pulses) are kept also in H-field waves. The amplitudes of two pulses are supressed by different slope with distance from ESD point. „Slow pulse“ is attenuated more rapidly than „fast pulse“.

The period of unintended oscilations corresponds with dimensions of metallic plate (HCP) more than with parameters of ESD generator equivalent circuit.

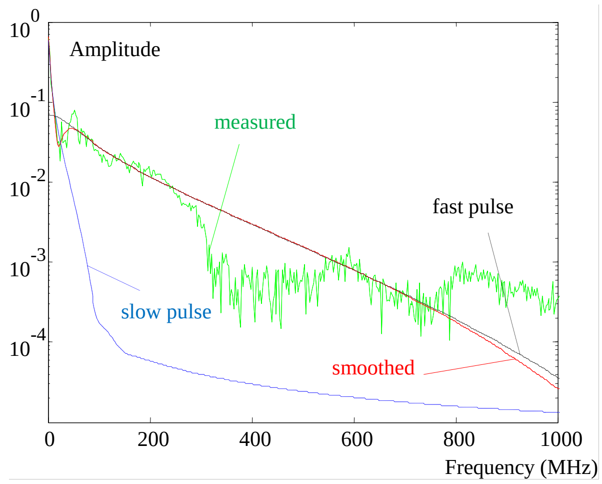

Fig. 8. Frequency spectra of measured and smoothed Residual – difference between measured and smooted curves for 40 cm distance.

Acknowledgement

This research was financially supported by Slovak Ministry of Education under grant No. 2003SP200280802, by the project VEGA 1/0963/12 and by the project PERFORM-ERA "Postdoctoral Performance for Integration in the European Research Area" (ID-57649), financed by the European Social Fund and the Romanian Government.

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Received 8 September 2012

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