Measurement of the magnetic field radiating by electrostatic discharge generators along various directions

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***Abstract*— The aim of this paper is the investigation of the transient magnetic field radiating by two generators of electrostatic discharges. Near field measurements have been conducted, a few centimetres far away from the discharge point (Pellegrini target). The Pelegrini target is mounted on the center of a grounded metal plane, inside an anechoic chamber. The measurements refer to three different directions in reference to the discharge direction. The experimental data show that each electrostatic discharge generator produces a different transient magnetic field. Furthermore, additional differences for the magnetic field produced by each generator are noted, depending on the direction that the measurement is conducted. Finally, comparisons of the magnetic field produced by each generator as well as useful conclusions for the decrease of the magnetic field are presented.**

***Index Terms*— ESD generators, magnetic field, magnetic field sensors, grounded metal plane.**

I. INTRODUCTION

Electrostatic discharge (ESD) is defined as the sudden transfer of charge between objects at different electrostatic potentials [1, 2]. The IEC 61000-4-2 [3] defines the procedures that must be followed during ESD tests on electrical or electronic equipment. The Standard's specifications over ESD tests include several parameters -referring to the ESD generator- such as the rise time, the peak or the current at 30 ns and 60 ns. Despite the fact that several ESD generators fulfill the Standard's criteria, the produced magnetic fields differ.

Wilson and Ma [4] were the first, who simultaneously measured the current and the electric field during ESD at a distance of 1.5 m. An investigation by Pommerenke and Frei [5] on the field produced by various ESD generators, using a grounded metal plane concluded that the field is stronger, when the plane is vertically placed rather than when it is horizontally placed. Leuchtmann and Sroka [6, 7] calculated the produced electromagnetic field. The comparison between theoretical data and experimental results proved a totally acceptable agreement for the magnetic field, yet not such a good one for the electric field. Two different field probes were used, giving different results, proving that the measurement of the electromagnetic field is quite a challenging task.

Benjamin [8] measured the magnetic field produced by ESD for various distances from 10 mm to 60 mm showing that the magnetic fields near an ESD can be predicted by a sequence of electric dipoles. Also, the peak of the magnetic field varies inversely proportional to the distance. In another work [9] they measured the optical radiation and the magnetic field generated by ESD along with their current signatures. The measurements showed that during the initial growth the temporal variation of the optical pulse is similar to the one of the current.

A recent publication of Pommerenke's team [10] notes the deficiency of the four parameters defined by the Standard and negotiates what the next revision of the Standard should include. The produced electromagnetic field by the ESD generators should be taken into account in order for limits and specifications to be defined.

This work aims to contribute to the upcoming version of the Standard through experiments that have been carried out at the facilities of our Laboratory. During last years it was observed that equipment under test (EUT) can pass the ESD test, when using a certain ESD generator and fail when using another, both cases referring to the same charging voltage and to the same discharge current. This arises from the fact that each ESD generator produces a different electromagnetic field, so the induced voltage differs. Furthermore, the experimental data note that each generator may result in a different way on an EUT, depending on its orientation. Such an observation has not been made until today and should be taken into consideration in the next revision of the Standard, in order to define the construction of each generator, as to achieve the same radiating electromagnetic fields in all directions.

II. MEASUREMENT SYSTEM

The ESD current experimental setup is shown in Fig. 1. The current and the magnetic field (H-field) produced by contact discharges for charging voltage levels of ±4 kV were measured simultaneously, by the 4-channel Tektronix oscilloscope model TDS 7254B, whose bandwidth ranges

Manuscript received April 21, 2006. The project is co - funded by the European Social Fund (75%) and National Resources (25%) - (EPEAEK II) – PYTHAGORAS II. G.P. Fotis is supported by a Ph.D study scholarship from the State Scholarships Foundation of Greece.

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from dc to 2.5 GHz. The used ESD generators were the NSG-433 and the NSG-438 of Schaffner. It must be mentioned that the NSG-438 has a basic station contrary to the NSG-433. The basic station of the NSG-438 was placed on the floor of the anechoic chamber and its horizontal distance from the middle edge of the grounded metal plane was 40 cm. The positioning of the high voltage cable was kept constant during the experiment procedure. The high voltage cable positioning of the station was very important and this is a basic difference between the two ESD generators, which affect differently the produced magnetic field. In order to reassure that the measurement setup would be unaffected by surrounding systems, the experiment was conducted in an anechoic chamber.

The temperature and relative humidity were measured and found in the range of 23 ± 2 ^{o}C and 40 ± 5%, respectively. In order for the current to be measured a resistive load was used, as the IEC [3] defines. This resistive load (Pellegrini target MD 101) [11] was designed to measure discharge currents by ESD events on the target area and its bandwidth ranges from dc to above 1 GHz. It was placed on the center of a 1.5m x 1.5m horizontal metal plane, which was placed 70 cm above the ground.

The H-field sensor that was used for the experiment was a ground based field sensor with active integration of D. Pommerenke [12]. It was placed at various distances (20, 35, 50 and 65 cm) from the discharge point on the metal plane and in three perpendicular directions (direction A, direction C and direction D) as it can be seen in Fig. 2. Measurements in direction B were not conducted due to the interference of the ground strap of the ESD generator. It is known that the position of the ground strap affects the falling edge of the current's waveform. In order to minimize the uncertainty of this fact into the measurement of the magnetic field the ground strap was in a distance of 1 m from the target as the Standard [3] defines and the loop was as large as possible.

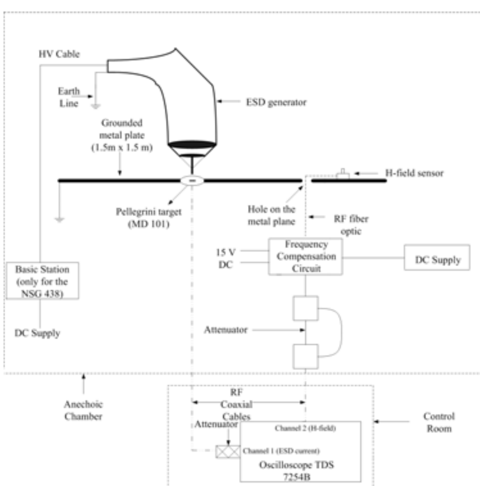

Fig. 1. Experimental setup.

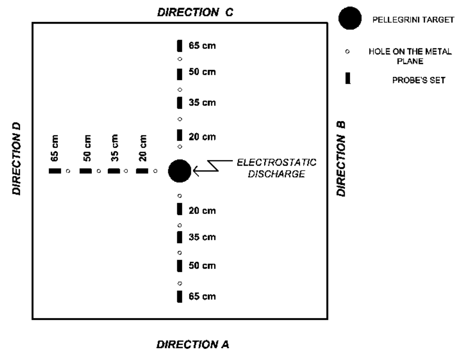

Fig. 2. The measurement points where the H-field sensor was placed.

III. EXPERIMENTAL RESULTS

The magnetic field's strength was measured using the experimental setup described previously. Representative waveform of the magnetic field's strength in common graph with the discharge current is depicted in Fig. 3. It is obvious that the magnetic field is proportional to the discharge current according to Ampere's law that relates the magnetic field's strength with the current. It can be also observed that the magnetic field starts with a flat line for the first 3 ns. The electromagnetic wave covers 20 cm in about 0.7 ns. The other 2 ns are attributed to the delay of the field sensor. Superposition of wave delay and probe results to a total delay of about 3 ns.

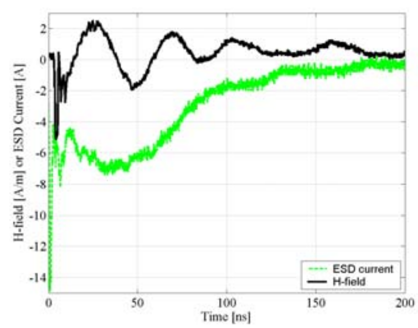

Fig. 3. ESD current and H-field for the NSG-438 ESD generator, 20 cm from the discharge point, in direction A (Charging Voltage= -4kV).

The peaks of the magnetic field's strength (H_{max}) for both NSG-433 and NSG-438 and for all three directions are presented in Figs. 4-6. The amplitude of the peak H-field decreases as the distance between the discharge point and the magnetic field sensor increases. This is in accordance to the remarks of [5], where comparisons of the magnetic field for the metal plane in horizontal position are presented. It should be also mentioned that the two ESD generators produce different magnetic fields due to differences in their construction and probably due to the different relays they are equipped with. It can be noted from all three figures that the magnetic field strength decreases as the distance increases, according to the 1/R factor (R is the distance from the discharge point). In direction C and D the magnetic field's strength produced by the NSG-438 is higher than the one produced by the NSG-433. Also, the magnetic field's strength for positive charges is higher than the one for the negative ones. This conclusion is not valid for direction A, where the NSG-433 produces in general higher magnetic field than the NSG-438. Moreover, negative charges produce higher field than positive charges. It must be mentioned that for the negative discharges a higher discharge current is measured and consequently higher magnetic field strength, while the discharge current is within the limits defined by the Standard [3] for the calibration procedure.

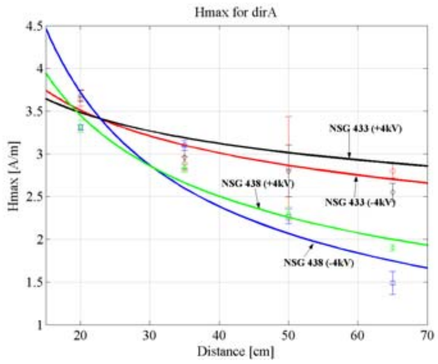

Fig. 4. H-field strength for both ESD generators in direction A for all four distances (20 cm, 35 cm, 50 cm and 65 cm) from the discharge point.

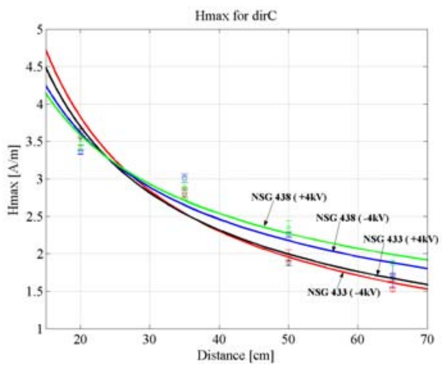

Fig. 5. H-field strength for both ESD generators in direction C for all four distances (20 cm, 35 cm, 50 cm and 65 cm) from the discharge point.

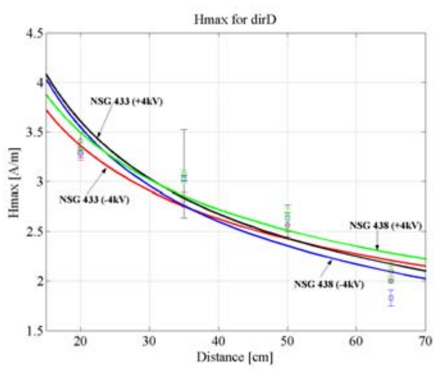

Fig. 6. H-field strength for both ESD generators in direction D for all four distances (20 cm, 35 cm, 50 cm and 65 cm) from the discharge point.

During the measurements, different magnetic field was noted for perpendicular directions, referring to the same discharge voltage, the same metal plane, the same distance between the sensor and the point of discharge and of course for the same ESD generator. The following Figs 7-10 show the comparison between the peaks of magnetic field's absolute value for all three directions.

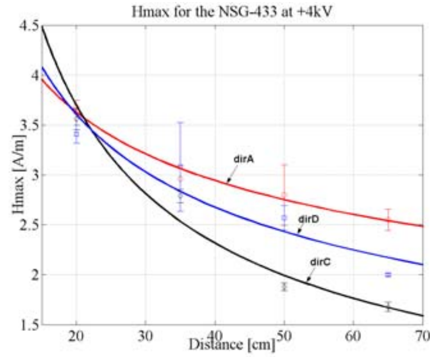

Fig. 7. H-field absolute value for the NSG-433 ESD generator for all four distances (20 cm, 35 cm, 50 cm and 65 cm) from the discharge point.

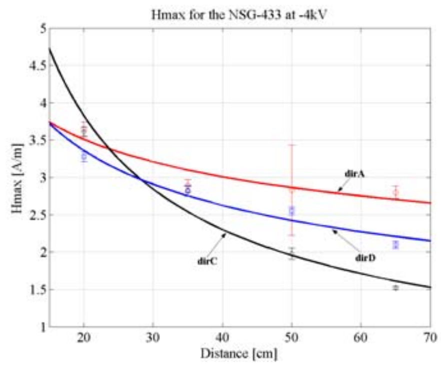

Fig. 8. H-field absolute value for the NSG-433 ESD generator for all four distances (20 cm, 35 cm, 50 cm and 65 cm) from the discharge point.

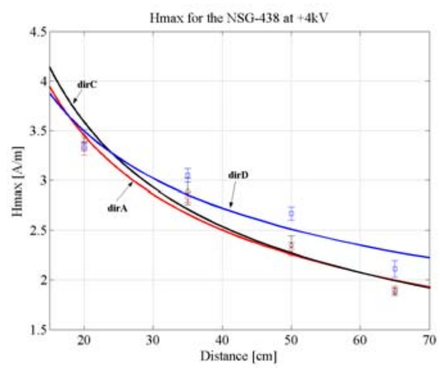

Fig. 9. H-field absolute value for the NSG-438 ESD generator for all four distances (20 cm, 35 cm, 50 cm and 65 cm) from the discharge point.

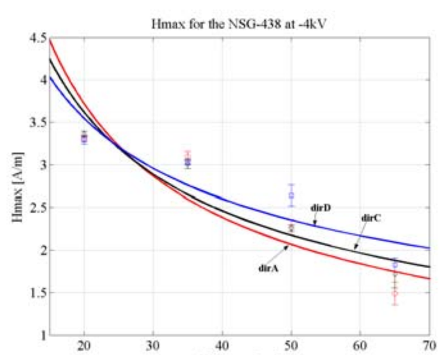

Fig. 10. H-field absolute value for the NSG-438 ESD generator for all four distances (20 cm, 35 cm, 50 cm and 65 cm) from the discharge point.

It is obvious that as far as the NSG-433 ESD generator concerns, the field generated in Direction A is stronger than the one generated in Direction D. Moreover, the field generated in Direction D is stronger than the one generated in Direction C. Consequently, the directions in which the H-field's peak is higher can be sorted as follows: Direction A > Direction D > Direction C. In the case of the NSG-438 ESD generator the H-field's peak can be sorted as follows: Direction D > Direction C > Direction A. These differences could be explained assuming that the circuit produces different magnetic field. Great attention should be paid at this fact because the orientation of the ESD generator could affect differently the EUT. For example if a test is carried out using the NSG-433 ESD generator and having the EUT placed in Direction C the result may be positive. On the other hand the same EUT may fail the exact same test if placed in Direction A, because in this direction the peak field is higher. It must be mentioned that different test results on the EUT may be obtained by different ESD generators. If the ESD generator is changed and the ESD generator's direction is the same the produced magnetic field is different and therefore the test result on the EUT may differ.

IV. Conclusion

The transient magnetic field produced by two different ESD generators and for charging voltages of ±4 kV was measured, when the Pellegrini target was mounted on a grounded metal plane. The comparisons showed that each generator produces a different magnetic field. Therefore, there is a need for this remark to be taken into consideration at the next revision of the IEC 61000-4-2, in order for the limits of the produced transient fields to be defined. It was also found that each ESD generator produces different magnetic field depending on the direction the measurement is carried out. This means that the produced magnetic field may differ not only from generator to generator but for the same generator as well. So, depending on the orientation of the ESD generator the induced voltages are different and therefore an EUT may pass the test with one orientation of the ESD generator and fail with another. It was also concluded that the magnetic field decreases as the distance from the discharge point increases.

There is a rotational asymmetry of the field distribution around the ESD generators, which may affect differently an EUT. Two possible reasons for this phenomenon are: a) Inside the ESD generator the high voltage relays have not rotational symmetry, b) The positioning of the return path and, additionally, the high voltage cable of the NSG-438 affects it. In the calibration setup the positioning of these cables is defined and the field measurements are reproducible, but when testing a EUT the positioning of these cables is not defined and the reproducibility of the field distribution is much weaker. The IEC Committee should take into consideration in the future revision of the Standard that the ESD generators should be marked on the direction that the field is the stronger. Also, during the verification the ESD generators should be tested on the produced electromagnetic field around 360°. The next revision of the Standard should include typical waveforms of the magnetic field that are produced by electrostatic discharges. It should also define the range of values for several magnitudes of the magnetic field (such as H_{max}, the rise time and perhaps values for the derivatives of the produced magnetic field). Should the above remarks be taken into consideration in the next revision of the Standard and particularly in the specifications for the design of the ESD generators, the uncertainty of the test results will be reduced.

Acknowledgment

The authors would like to thank Professor David Pommerenke of the Missouri-Rolla University in the USA and Dr. Jan Sroka of Schaffner for their very useful comments and technical support of the work presented here.

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